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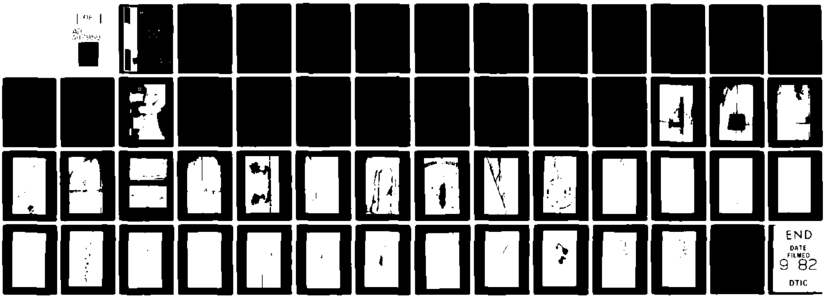

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FLOW VISUALIZATION WATER TUNNEL— ITS CONSTRUCTION AND CAPABILITIES

by
G. A. Dobrodzicki
National Aeronautical Establishment

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FLOW VISUALIZATION WATER TUNNEL — ITS CONSTRUCTION AND CAPABILITIES

LE TUNNEL HYDRODYNAMIQUE DE VISUALISATION DES ÉCOULEMENTS DESCRIPTION DE SA CONSTRUCTION ET DE SES POSSIBILITÉS

by/par

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SUMMARY

The intention of this report is to demonstrate the utility of the flow visualization water tunnel in the field of experimental fluid dynamics and also provide guidance to its prospective users.

A brief description of the facility and its ancillary equipment is followed by a short description of the flow visualization techniques.

To emphasize the diversity of subjects tested in the water tunnel, a list of typical experiments and a number of photographs are presented.

SOMMAIRE

L'objet de ce rapport est de démontrer l'utilité du tunnel hydrodynamique de visualisation des écoulements dans le domaine de la dynamique des fluides expérimentale et également de fournir certaines indications utiles à ses utilisateurs potentiels.

Une courte explication des techniques de visualisation utilisées est complétée par une brève description de l'installation et de ses équipements auxiliaires.

On présente également une liste d'essais types et quelques photographies pour souligner la diversité des problèmes pouvant être analysés à l'aide du tunnel.

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FLOW VISUALIZATION WATER TUNNEL – ITS CONSTRUCTION AND CAPABILITIES

1.0 INTRODUCTION

In the field of fundamental and applied fluid dynamics, particularly in aerodynamics, there are many situations in which it is difficult to picture the exact nature of the flow field. The Flow Visualization Water Tunnel provides one experimental solution to this problem. In general design it resembles a small wind tunnel, and although water rather than air, is the working medium, it has long been realized that the flow properties of liquids are similar to those of gases, as long as the gas velocities to be simulated are low in comparison with the speed of sound. The advantage in using water for subsonic flow visualization is that the path of the flow is easily made visible by illuminating tracer particles, dye filaments or hydrogen bubbles suspended in the water. The low velocities generally used in the water tunnel make possible direct visualization of both steady and unsteady flows. With adequate lighting, photography is also relatively simple and produces striking results.

The technique has limitations. The combination of small model and low fluid velocities (less than 10 feet per sec) limits the Reynolds number to rather low values. Fortunately, the kinematic viscosity of water (the ratio of molecular viscosity to density) is about 1/15 of that of air at normal room temperatures and hence the Reynolds number is 15 times greater in water than in air at the same scale and speed. However, its value will generally be lower than that achievable in large wind tunnels and still lower than the Reynolds numbers of aircraft in flight or large non-aeronautical structures exposed to natural winds. This limitation must be constantly borne in mind in the interpretation of experimental results.

The simplicity of the water tunnel and the extreme clarity and detail with which it displays real flows in two and three dimensions make it a useful laboratory facility for both fundamental and applied fluid dynamics investigations. This report describes the National Aeronautical Establishment Water Tunnel and briefly reviews a number of experiments that have been carried out by National Research Council Canada personnel and by industrial users.

2.0 GENERAL DESCRIPTION OF THE NAE WATER TUNNEL

The NAE's Flow Visualization Water Tunnel, located at the National Research Council Canada, Montreal Road Laboratories, in Ottawa, has a rather colorful history. It was designed and built in 1939 at the AERODYNAMISCHE VERSUCHSANSTALT, GOETTINGEN, Germany and throughout World War II remained a research facility in the services of the German Aircraft Industry.

After the war, under the operation code named "Surgeon", which involved dismantling and appropriating certain German industries by theAllies, the tunnel was shipped, via RCAF Enemy Equipment Unit to Canada and finally found a permanent place at the Low Speed Aerodynamic Laboratory of the NAE. An extensive modernization program took place in 1960, greatly improving the tunnel's performance and extending its operational versatility.

The water tunnel resembles a conventional closed circuit wind tunnel, is constructed of mild steel sheeting and contains 350 gallons of water. The working section component spans the gap between the 4 to 1 contraction and the return leg duct. The working sections dimensions are — width 10 inches, height 13 inches, length 32 inches. Glass plates form the front and the bottom sides, while the back wall contains a 10.25 inch diameter turntable, with a retaining ring, calibrated in degrees. Removable plates close the working section on top, thus preventing the surface disturbances from reaching the model. Figure 1 gives the general view of the facility with its ancillary equipment and control panel.

In most cases the models are mounted internally on the turntable, with the angle of attack adjusted from the outside. A string attachment offers alternative support. Schematic drawings (Figs. 2, 3, 4) give the prospective user an idea of how their models can be installed. There is room for improvisation — for instance models of snowplow truck or a section of a city are mounted on the top plate,

hanging upside down, since the light source is beneath the bottom glass plate. By placing a large mirror under the working section, the model's underside can be viewed; another mirror located downstream shows the rear portion of the model and the flow in a plane normal to the free stream.

Water is circulated by a 15 inch diameter, four-bladed, cast bronze propeller, situated in the return leg of the tunnel and driven by a 6.35 hp, 240v dc motor. Water velocities in the working section are infinitely variable from 0.2 feet per second to 10 feet per second, and accurately governed by means of a Ward Leonard motor speed control. These velocities correspond to a range of Reynolds numbers per foot of 1.3×10^4 to 6.5×10^5 at water temperature of 20°C. For the tunnel velocity calibration chart see Figure 5 and for Reynolds numbers, Figure 6.

The inverted manometers measure the speed of the free stream. A kerosene/water manometer for velocities up to 5 feet per second and the second, an interconnected air/water manometer for velocities up to 10 feet per second. Both are linked to the pressure tap outlets at the tunnel contraction.

Water temperature may be varied from 8°C to 30°C providing a range in Reynold number for low tunnel speeds. This is particularly helpful when dye filament is used as the visualization medium. In one example, for the flow over a fuselage, the Reynolds number was increased by 36% at the same tunnel speed. Since ambient temperature of the water from the mains reaches 22°C during the summer months, it is not always possible to realize lower Reynold numbers. A turbulence damping screen, 18 inch $\times$ 14 inch constructed of 0.01 diameter copper wire is available for installation at the entrance of the working section. To eliminate the boundary layer of the working section's floor, an electrically operated moving ground board may be inserted.

Blowing or suction on the models can be accomplished with the aid of a pump, which draws water from mains or recirculates the water from the tunnel. This task is performed by the Ingersoll Rand water pump, which has a capacity of 60 gallons per minute. The blowing or suction mass flow is measured by a standard orifice connected to mercury manometers (see Fig. 7). Two compressed air outlets with regulated pressure 0 to 30 and 0 to 80 pounds per square inch are located close to the working section. Two more air outlets, 100 psi pressure are close by. The air is being used as a bubble producer for visualization, to run the air turbine for powered models or as a supply jet for fluidic devices. The water pump blowing and suction circuit and the air pressure circuit are shown in Figure 8. All operating controls are centralized in one console with gauges, valves and manometers within the immediate vicinity.

The various models tested over the years cover a wide and diversified range: aeroplanes, automobiles, trucks, blimps, bridges, buildings, ships, snowmobiles, combustion chambers, sports stadiums, propellers, airfoils, ellipsoids, cylinders, fluidic devices, etc. Since the flow past the models is subject to constraint, it is advisable to limit in size the bluff body type models to a frontal area of less than 5% of the working section's frontal area and normal lifting wings spanning the tunnel to a chord of 2.5 inches.

To avoid blockage of the light from certain regions of the flow field, in most cases the models are fabricated from transparent materials such as plexiglass, although some were made of wood, brass or aluminum. Non-transparent models are usually painted black to reduce glare, unwanted reflections.

3.0 FLOW VISUALIZATION TECHNIQUES

A very explicit and simple flow visualization technique involves observation of highly reflective tracer particles, suspended in the water, illuminated by an intense light source. For this purpose, aluminum powder has been found most suitable. The amount of aluminum powder injected into the water is arbitrary, but experience has shown that the effect of reflected light (and hence the photographic exposure) varies widely with the quantity of powder in suspension. It is therefore

desirable to keep the amount of aluminum constant from test to test, so this particular variable can be eliminated from photographic considerations. This has been accomplished by using a standard light meter to monitor the reflected light when saturating the water with aluminum powder. The figure of 3.2 candles per square foot has been chosen as permanent value for all tests (see Fig. 9). For examples of aluminum method, see Figures 10 through 19.

In some cases, when perusal of the local detail of flow is desired such as in jets, boundary layers, wakes, the flow must be made visible only in those regions. Widely employed method is to use fluorescent pigments dissolved in water and introduced at appropriate locations into the flow around the model. This is accomplished by emission of dye either through tiny holes distributed along the body of the model or through probes which can be accurately positioned in different points of the working section by means of a traversing gear arrangement. These dyes are synthetic, inorganic chemical, with the property of emitting visible light of constant intensity when exposed to a uniform source of radiant energy of the proper wave length. A commercial product, called FLUORESCEIN (Anacheima Chemicals Ltd), which yields a bright green filament is most commonly used in a concentration of three grams to four liters of water. Contamination of the main flow is slow and it is possible to run tests of two to three hours duration without serious loss of contrast between the filament and its background. For some tests more than one colour of dye is required. Multi-coloured water dyes, manufactured by Shannon Luminous Materials have been successful because of their vivid colouring and brilliancy, particularly when exposed to ultra-violet light source (see Figs. 23, 24 and 25). Deployment of colour dyes, illuminated by a mercury vapour lamp is demonstrated by Figures 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37 and 38. Use of ceramic spheres and polystyrene beads as tracers has been investigated, but the process proved to be inferior to aluminum particles method, because spheres and beads tend to settle on the bottom of the tunnel, thus upsetting uniform and lasting concentration, so important for photography. Air bubbles seemed to work well with a model air cushion vehicle, remaining in the vortex cores or in the fluid rotation.

The phenomenon of electrolysis of water, where hydrogen is produced at the cathode and oxygen at the anode provides a satisfactory method of production of continuous filaments of tiny bubbles applicable to flow visualization. Since the volume of hydrogen generated is twice as large as that of oxygen, hydrogen bubbles are most frequently used for flow visualization. Their buoyancy does not seriously impair the technique.

A platinum wire cathode, 0.005 inch diameter crimped by passing between a pair of meshing gear wheels was mounted at the upstream end of the working section. The anode was grounded to wall of the tunnel. The passage of an electric current from a 100 volt, 1.5 amp dc power supply produced a large quantity of tiny hydrogen bubbles along the length of the cathode wire. Then the bubbles are swept towards the apices of the kinks in the wire and from there released into the flow forming parallel filaments, which follow the streamlines of the flow (Fig. 20). In another case, a flat plate delta wing, made of brass was painted over, except along the leading edge. The area devoid of paint served as the bubble producer, and with the wing at small incidence to the flow, the hydrogen bubbles were caught in a rolling motion generated by the leading edge, vortex shed from the exposed edge of the wing (Fig. 21).

The principal source of light used to alluminate the flow in the working section consists of a high pressure quartz mercury vapour lamp, 12 inches long rated at 1200 watts and enclosed in an air-cooled housing. This assembly is located on a calibrated grid, under the transparent floor of the working section. The light is projected upwards and focused through half cylindrical plastic lens, forming a vertical plane of light, 1.5 inches wide at the bottom and 0.75 inch at the tunnels top. Normally, the models are viewed with the plane of light parallel to the direction of the flow. The oblique mirror behind the working section reveals the rear portion of the model, looking upstream, with the light plane relocated normal to the flow. For examination of the bottom side of the model, the lamp housing is placed in a cage outside the front glass window. In this manner, a horizontal plane of light is obtained and the model can be viewed in a large mirror underneath, canted 45°.

The lamp operates on external frequencies of 60, 120 and 180 cycles per second. Since the light flashes twice per cycle, particles in the flow are illuminated at the rates of 120, 240 and 360 times per second, providing an accurate timing method over the complete range of water velocities. This intermittent flashing causes a particle to appear as an interrupted streak on a photograph, thus supplying the displacement and time information from which flow velocities can be calculated.

Interesting photographic results have been realized by the introduction of so-called "black lights". These are the lamps which produce primarily near-ultraviolet radiant energy in the 320-380 millimicron range, and when directed at the fluorescent elements, create a brilliant glow enhancing the variegation of colours. Other available lighting media include photofloods, electronic flash and strobes.

4.0 PHOTOGRAPHY

1. 35 m/m M3 Leica with direct vision finder Visoflex II; lenses — Elmarit 90 m/m f2.8, Sumicron 90 m/m f2.0, plus, for extreme close-up application special adaptors, permitting to focus as close as 14 inches from the subject.
2. 4 X 5 Graflex Graphic; lens — Lenar 135 m/m f4.7, plus, Land Polaroid attachment.
3. 16 m/m Arriflex Movie Camera.
4. 16 m/m Mitchell Movie Camera.

Special heavy duty Linhoff tripod allows to mount the cameras in every conceivable way around the working section. A wide range of 35 m/m films has been extensively tried for optimum results. Good pictures have been taken with moderate to high speed panchromatic films. Most commonly used films for black and white photography are Kodak Plus X and Kodak Tri-X, and for color, Kodak High Speed Ektachrome (daylight).

The Flow Visualization Laboratory has a well equipped dark room for processing the most commonly used black and white films and enlarging facility able to produce prints up to size 11 X 14 inches. Thus photographic results may be obtained with little delay for qualitative inspection and analysis.

5.0 SOME PROBLEMS INVESTIGATED IN THE WATER TUNNEL

A 1/2 inch diameter cylinder in two dimensional flow demonstrates the wake structure — the formation of regularly alternating vortices, sometimes called "the vortex street" (Fig. 28). This periodicity occurs in the Reynolds numbers range frequently encountered in the field of engineering and science. Reference 1 indicates the analysis of the above phenomenon and its implications in wind induced oscillations of structures.

The water tunnel observations of the flow around a 3-1/2 inch, 3-bladed propeller with its axis of rotation normal to the free stream revealed, at high advance ratios, that the wake is composed of two main trailing vortices and a third lying between these (Fig. 18 and Ref. 2). In case of a wing submerged lifting fan two areas of interest were investigated: a) the nature of interactions between the fan and the airfoil, thereby, providing some comprehension of the flow deviations that cause the large lift, drag and pitching moment increments (Ref. 3); b) the interaction between the wing and the fan efflux (Ref. 4). A typical photograph is shown in Figure 10.

The salient features of te rolled-up vortex sheets shed from the side edges of a flat plate are clearly defined in Figure 21 (also Ref. 5).

Observation of the vortex wake of a lifting fuselage, similar to those on rear-loading transport aircraft disclosed that, for negative incidence, the flow adjacent to the body and in the wake was composed of two separate vortices. Estimates were made of the vortex strength at two different Reynolds numbers; the vortex strength seemed to grow nonlinearly with incidence (Figs. 29, 30 and Ref. 6). Suction was used to control circulation about a two-dimensional airfoil with a zap-flap and helped to eliminate the turbulent wake, by turning the flow through large angles, with a large increase of lift (Ref. 7).

The exact nature of the flow over a ship's structure was required in connection with the design of stacks, which would disperse the smoke clear of the decks and also to determine the location in the distorted flow field where velocities were the same as the undisturbed flow velocity (Ref. 9).

An unpleasant discovery occurred in the high-speed icing wind tunnel. An intense noise, emanating from the heat exchangers developed, threating to endanger the structural integrity of parts of the tunnel. To visualize the interaction between the tubes of the heat exchanger, several arrays of one inch diameter acrylic rods were positioned in the water tunnel. The photographs were taken by a camera moving at the same speed as the free stream (Ref. 11).

The proposed refinement of the design of a bridge originated after exposing two models of sections to flow visualization (Fig. 15). The comparison of the flow over the two sections show that the original section displays a large wake and a separated flow region on the upper surface near the leading edge. The flow over the improved section, equipped with edge extensions remains attached to the upper surface, and forms a narrow wake. Consequently, the drag from the improved section is much smaller (Ref. 12).

In the initial stages of development of the fluidic velocity sensors, the *modus operandi* of the supply jet making its impact on the receivers was of great importance. The jet was made visible by injection of the fluorescent dye into the pressure chamber (Fig. 31 and Ref. 13).

To determine the extent of turbulence in a cascade jet logic element, a transparent model incorporating 11 jet outlets was built. In this device, it was demonstrated that, which turbulence exists within the principal cavity, the jets and their interaction are laminar (Ref. 14). In Figure 24 the supply jet is shown impinging on the receiver where dynamic head is imposed. The second picture, Figure 25 shows the supply jet being deflected by a control jet with the resultant loss of total head impinging on the receiver (Ref. 15).

The characteristics of natural low-level winds and their effect on the environment were the subject of intensive studies in NAE wind tunnels. A water tunnel model, consisting of a row of boundary layer generating three inch high spires at the upstream extremity and a group of 1-3/4 inch high square blocks, simulating a portion of a modern city was assigned to visualize the flow (Fig. 34 and Ref. 16).

Colour photograph in Figure 23 allows close observation of the deceleration of the flow on the rear portion of the ellipsoid (Ref. 28).

A project for the U.S. Navy called for a study of the behaviour of four cycloidal propellers. The moving colour picutres were taken by the camera rotating in unison with the propeller assembly. Loss of bauxite dust from large ship unloaders was examined with two small scale models. Passive aerodynamic fairings and suction by pumping reduced the dust loss by 90% (Ref. 22).

Original snowplow truck in operation, with high billboard at the back created high turbulence. The snow cloud in its wake obscured vision for faster vehicles coming from behind, and presenting grave danger. Turbulence minimizing configuration — removal of billboard, opening of back gate, shaping down sand ballast and installing a deflector — has been devised and accepted by the highway authority (Figs. 32, 33 and Ref. 24).

Turbulent flow around a tractor trailer causes considerable drag and instability. To make the flow more laminar, and thus reduce the drag, a cab deflector and rounding of the edges of the trailer have been introduced. This resulted in a substantial saving in fuel consumption and improved handling of the rig (Figs. 37, 38 and Ref. 24).

A study of the acceleration of neutrally buoyant spheres in a uniform flowing fluid revealed, that, after release, the sphere tends to overtake its own wake (Ref. 19).

Pursuant to experimental program in the 30 inch X 16 inch supersonic wind tunnel, investigating the effect of body vortices on dynamic and static cross derivatives of modern aircraft with long forebodies, a water tunnel model was subjected to flow documentation process. The model was sting-mounted on a movable section, allowing continuously to vary the angle of attack. Green and red dye filaments visualized the body vortices; symmetric at the angle of attack of 25° and then when the angle was increased to 45°, one of them, at random would hook over, forming an asymmetric pattern (Figs. 26, 27 and Ref. 21).

The three dimensional turbulent wall wakes produced by several basic obstacles, e.g.: a cube, are being studied both analytically and experimentally. A visualization program in the water tunnel was undertaken by visual observation, the flow conditions deduced indirectly from readings taken in the wind tunnel. The flow pattern around and behind a cube is illustrated in Figure 12.

In co-operation with Hydro Québec, an extensive investigatio[illegible]eing made in the Low Speed Aerodynamics Laboratory on the problem of sub-conductor gall[illegible]g of high voltage transmission wires. The galloping is a result of the aerodynamic interaction [illegible]ween cables, which are mounted in bundles (Fig. 14).

Following are more examples, briefly described, to give poten[illegible]'s further information and insight as to the possibilities of the water tunnel's capabilities:

1. A model of terrain was tested to render assistance in the investigation of an airplane crash. It was suspected that the direction of wind may have varied rapidly with the altitude in the valley.

2. Two standing vortices, discovered trapped within the section of a bridge indicated possible cause of the bridge's collapse.

3. Ventilator scoops on a bus.

4. Destroyer escort — turbulence over helicopter bridge.

5. Various aspect ratios of triangular and rectangular bluff bodies.

6. Wall jet in streaming flow (Ref. 20).

7. Station wagon — combinations of slats and skirts in an attempt to keep the rear window clear.

8. Sports Stadium — suitable locations to plant trees, in order to shield the playing field from the effect of ground winds.

9. Flow around the tips or air probes.

10. Flame tube of a turbo-prop engine — to improve the passage of gases, thus ensuring good mixing (Fig. 19).

11. Downhill ski racer — preliminary examination to the tests of National Ski Team members in the wind tunnel.

12. Interaction of hydro cables.

13. Another terrain model — investigation of a helicopter crash.

14. Three types of U.S. Air Force transport aircraft — boundary layer separation (Fig. 22).
15. RCAF fighter airplane — the effect of eingine exhausts on the elevtors.
16. Bee shelter — new design for portable alfa-alfa beehives in open prairie environment.
17. Varous shapes of spires — generators of simulated ground boundary layer.
18. Tumbling airfoil — several models of the NRC's Crash Position Indicator Unit.
19. Coal stock piles — different types of fence to prevent coal dust being blown off by wind.
20. Snowmobile — improved windshield and air scoops in front of the cockpit (Fig. 35).
21. Automotive cooling fan blade — visualization of vortex shedding (Ref. 23).
22. The formation of the trailing vortices or contrails has been demonstrated with the aid of the vortex generator (Fig. 17 and Ref. 25).
23. Wing section of an insect for CBC TV show.
24. Model of an insect, actually flapping its wings.
25. Sand dollars — flattened disc like echinoderms — their shapes governed by flow of water.
26. Airship hangars — new concept of rotating shelters.
27. Rotating wind mill blades.
28. Various fluidic devices.
29. Flow over magnetic levitation vehicle.
30. Suitable fairings on a racing motorcycle (Fig. 36).

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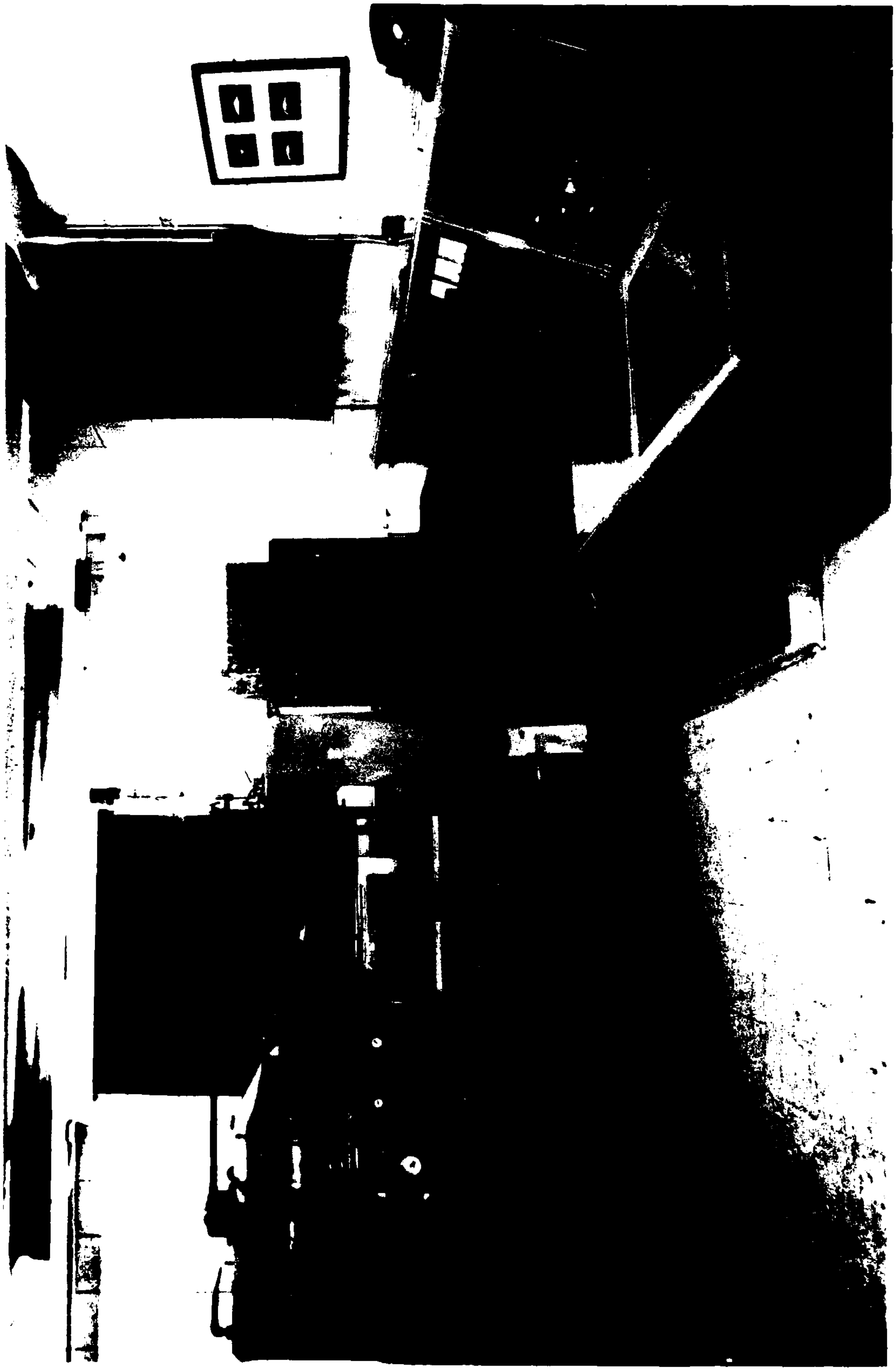


FIG. 1: GENERAL VIEW OF THE WATER TUNNEL

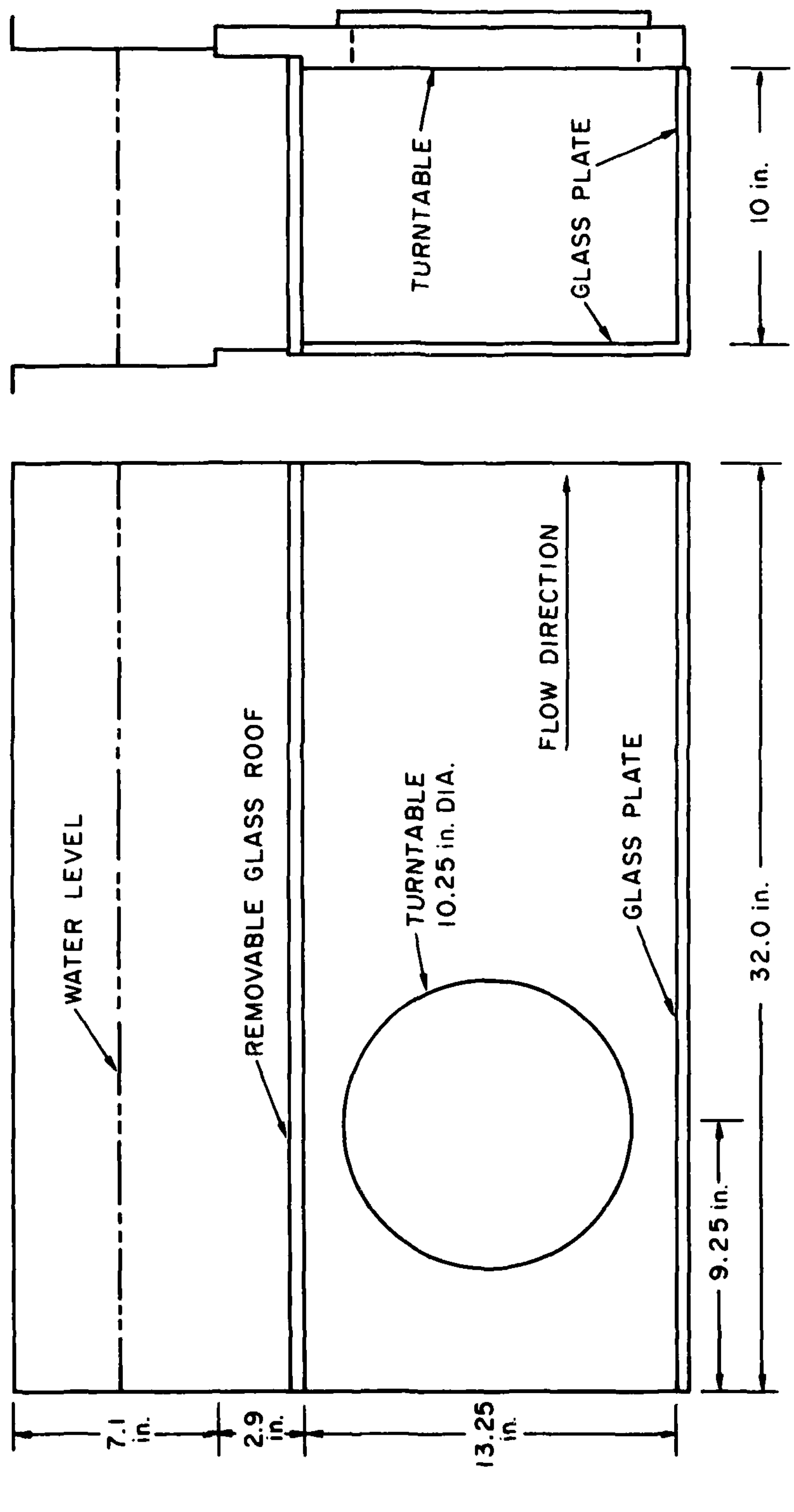


FIG. 2: WORKING SECTION

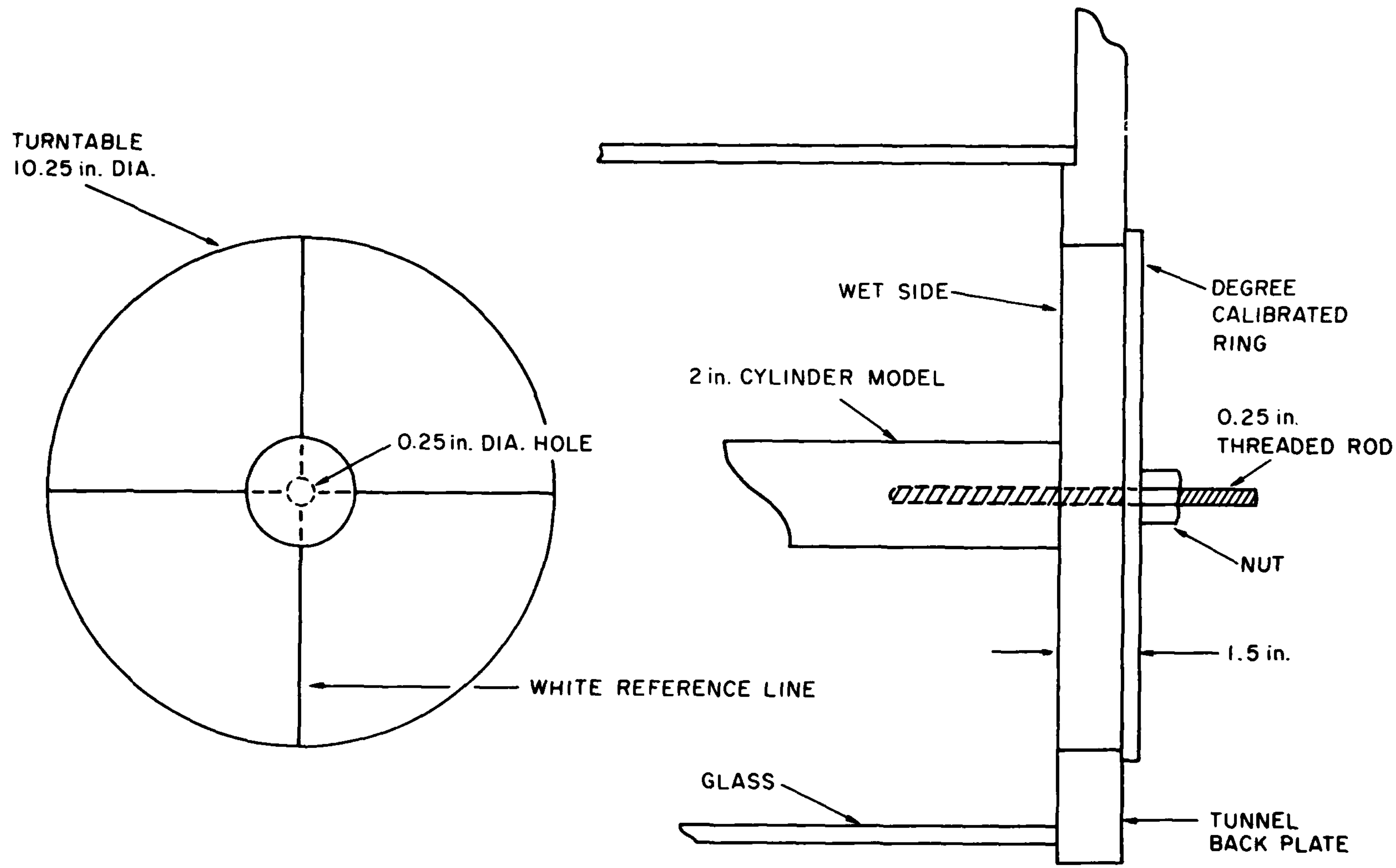


FIG. 3: METHOD OF MOUNTING MODELS ON THE TURNTABLE

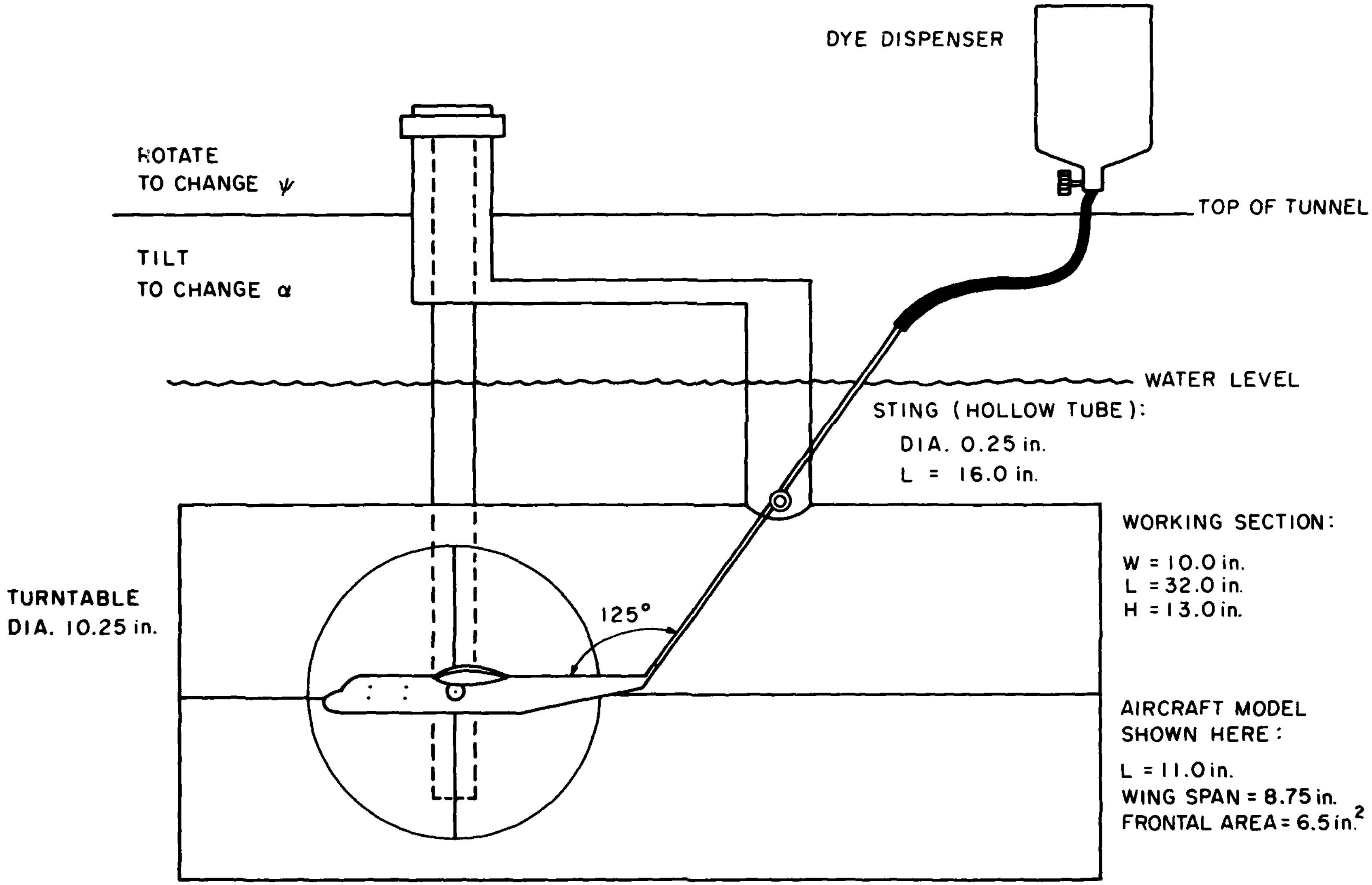


FIG. 4: STING MOUNT FOR WATER TUNNEL MODELS

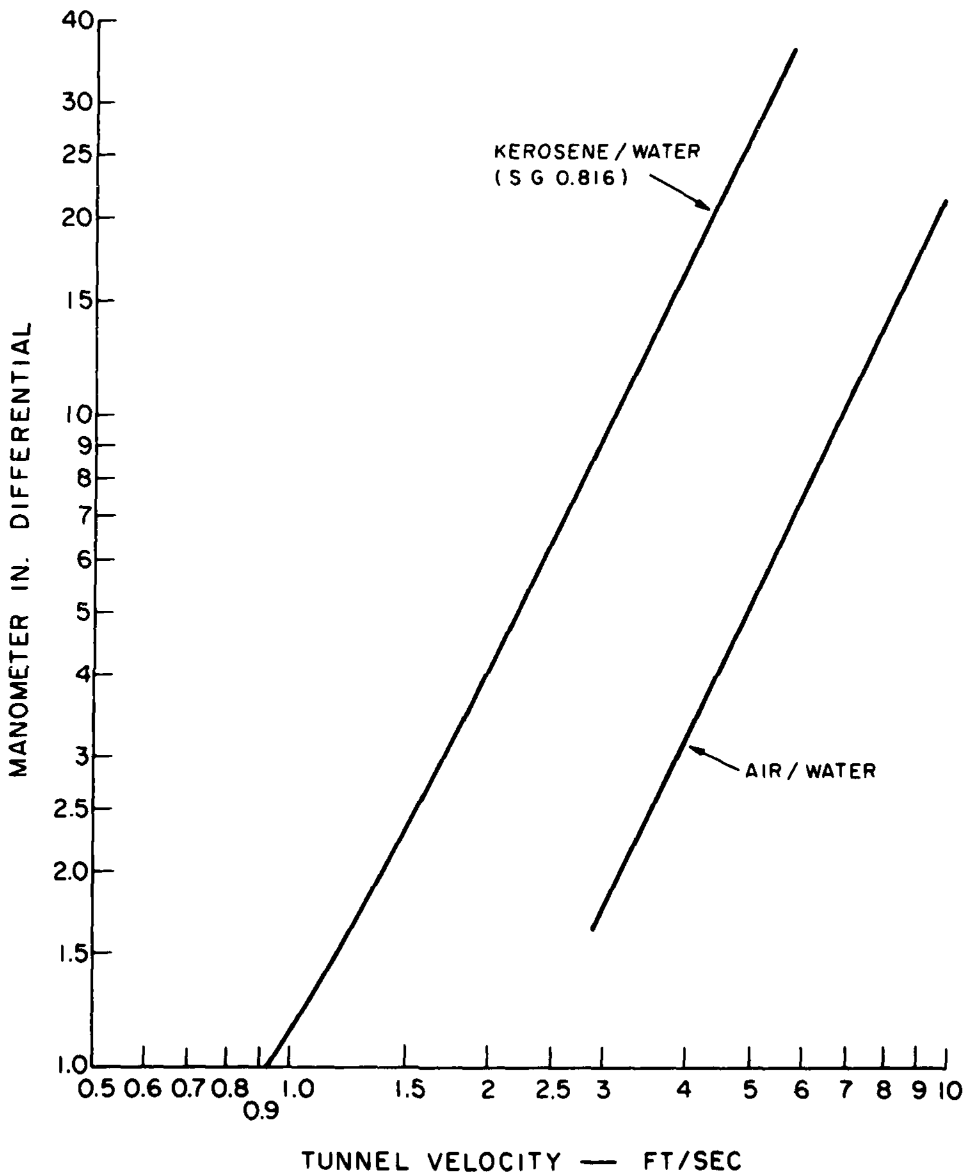


FIG. 5: FLOW VISUALIZATION WATER TUNNEL – VELOCITY CALIBRATION

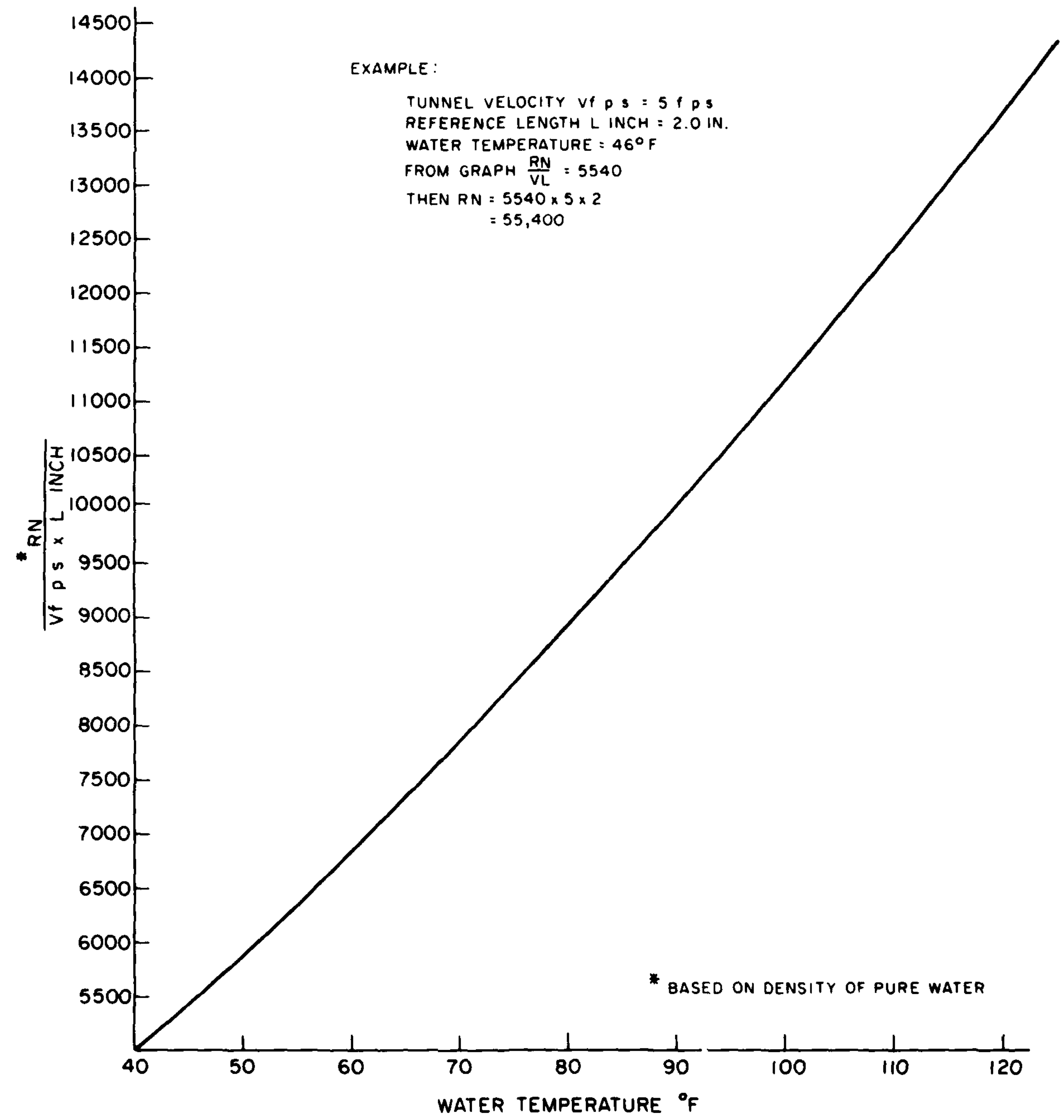


FIG. 6: RN CHART – FLOW VISUALIZATION WATER TUNNEL

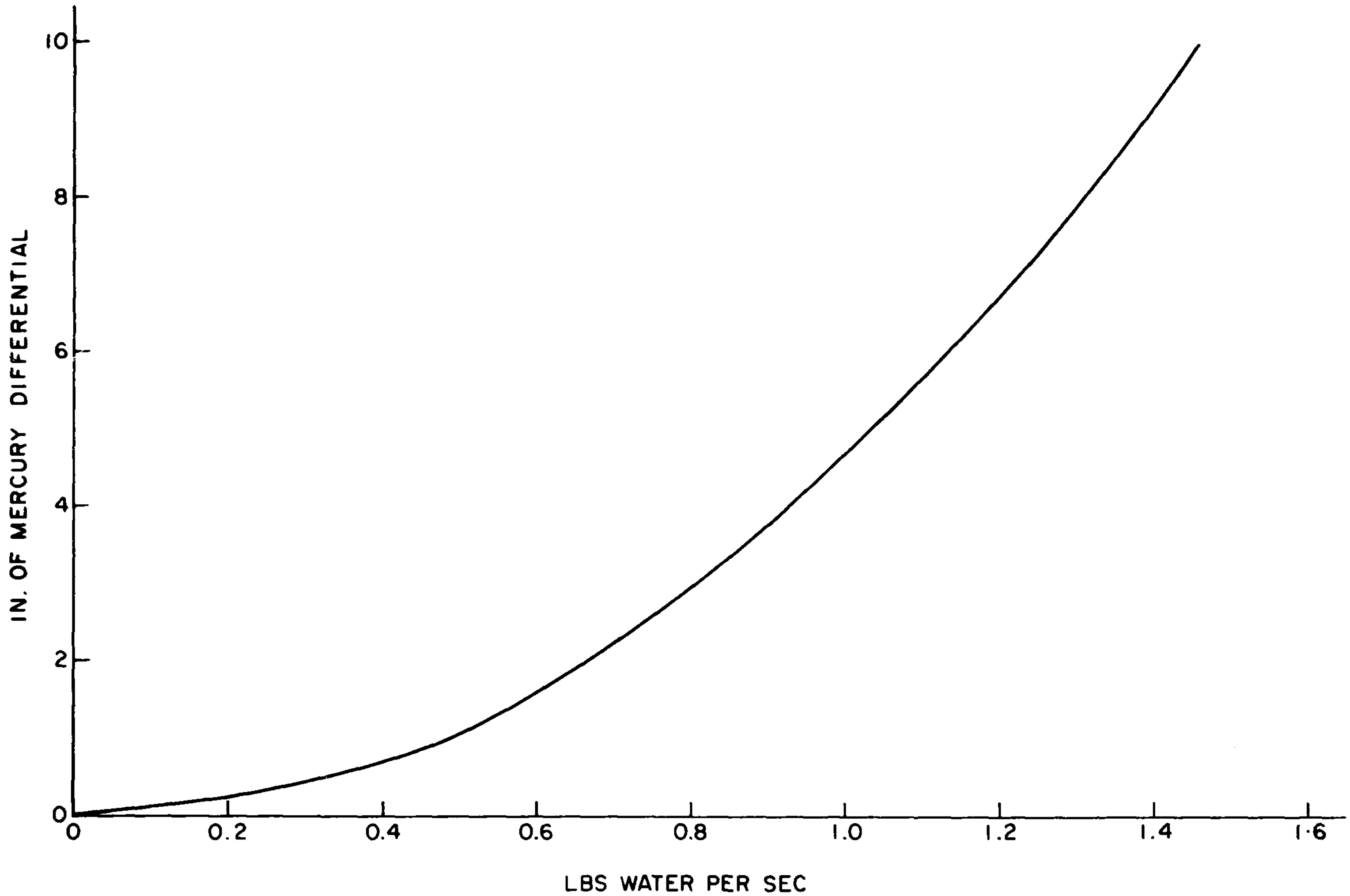


FIG. 7: FLOW VISUALIZATION WATER TUNNEL — CALIBRATION OF 3/4 INCH ORIFICE FLOWMETER

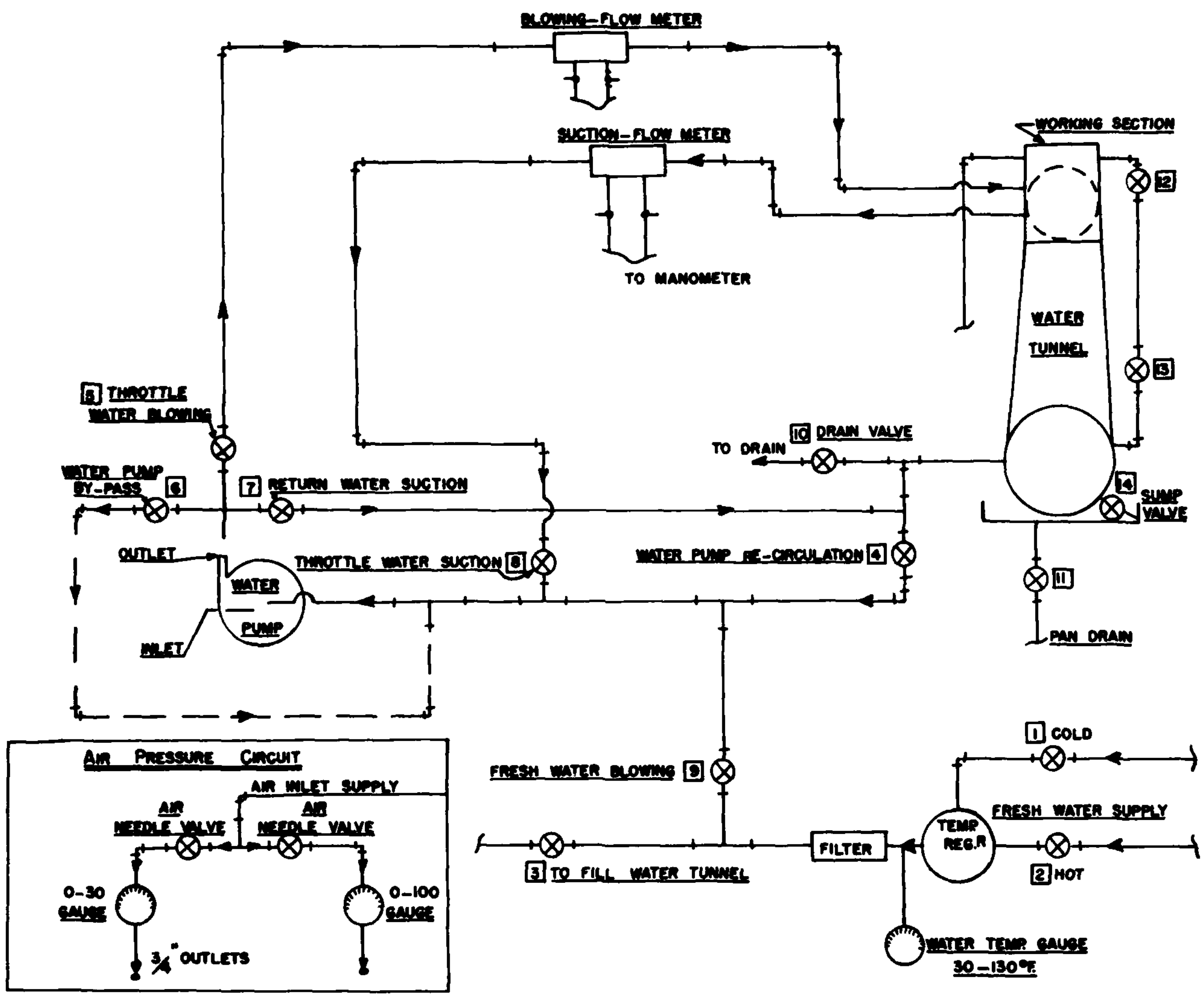


FIG. 8: WATER PUMP BLOWING AND SUCTION CIRCUIT – WATER TUNNEL

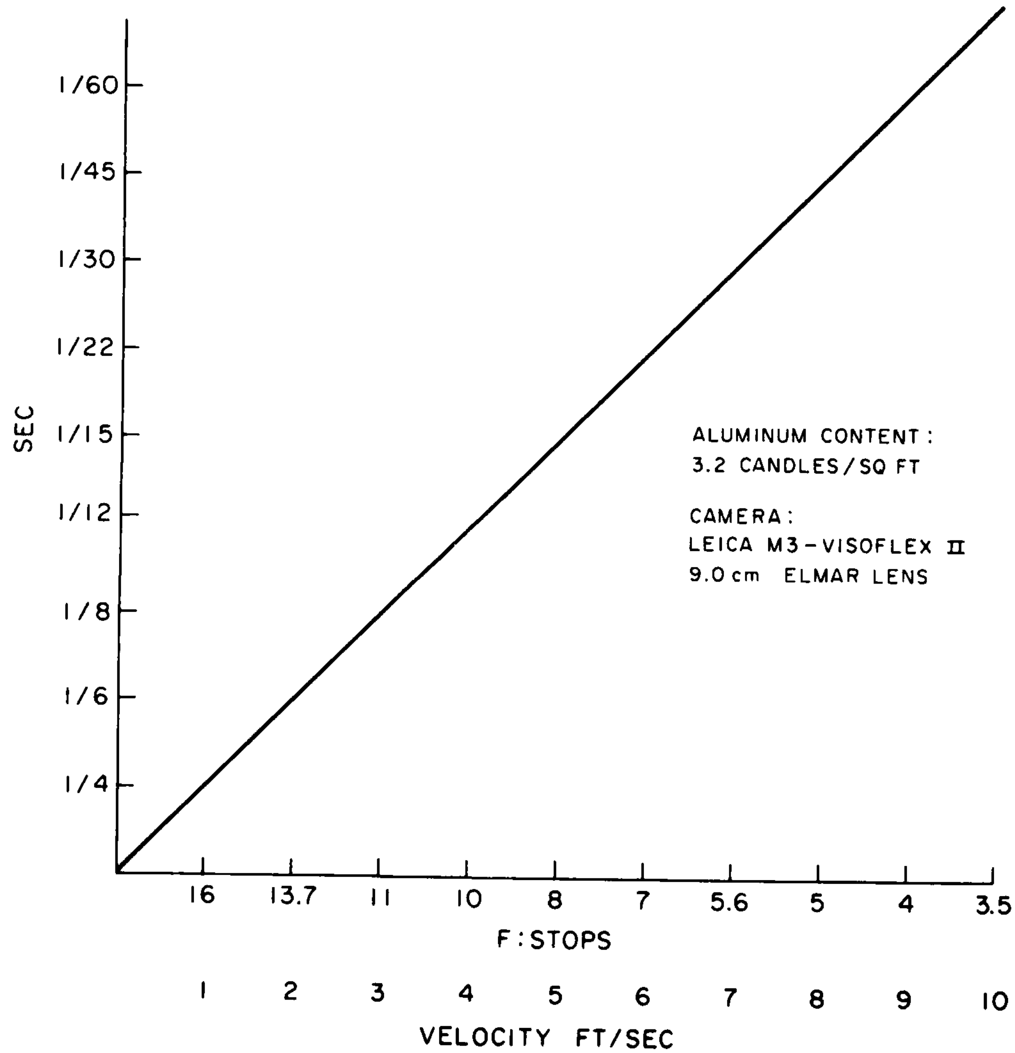


FIG. 9: WATER TUNNEL – TIME F STOP VERSUS VELOCITY PLUS X PAN FILM

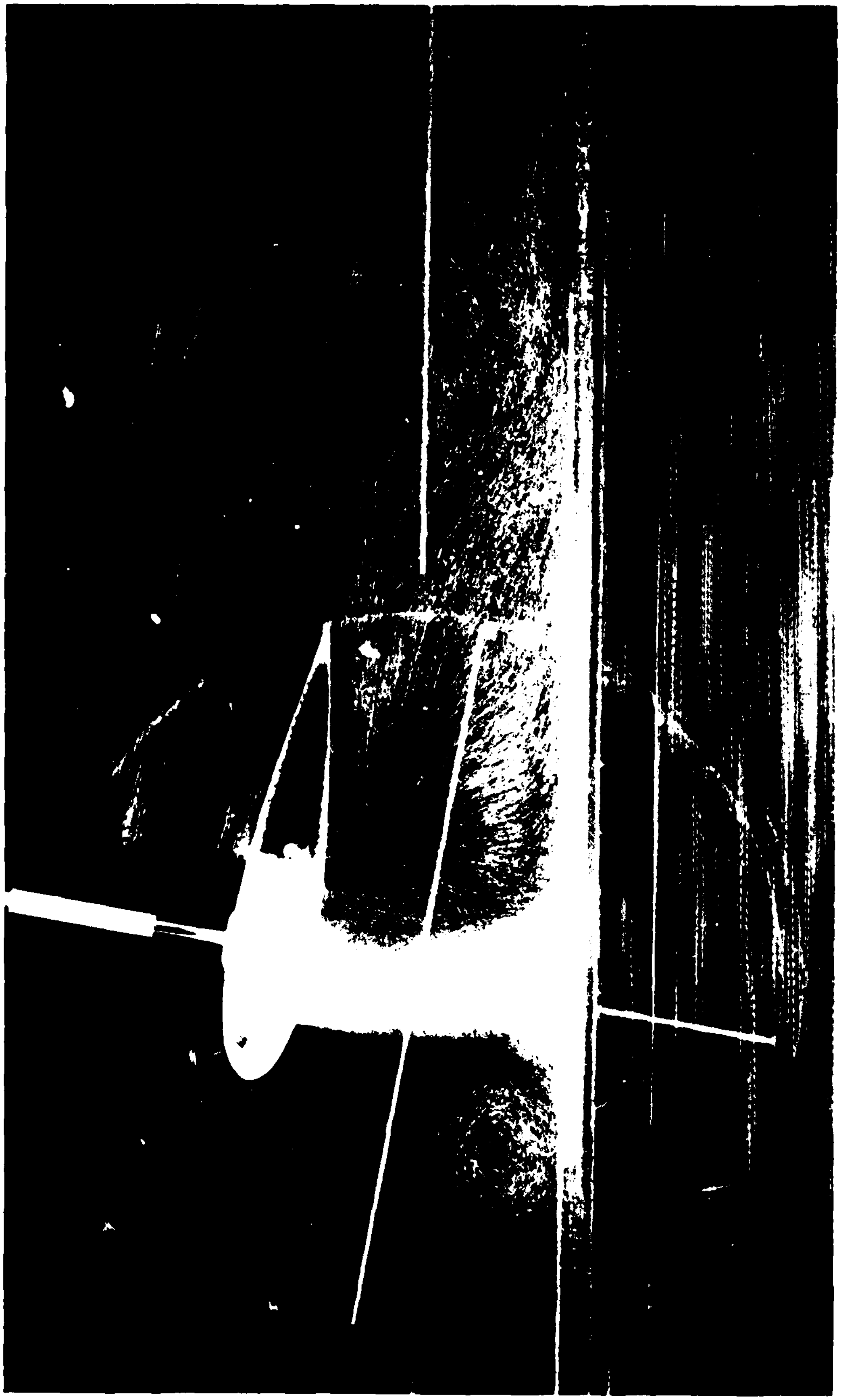


FIG. 10: WING-SUBMERGED LIFTING FAN

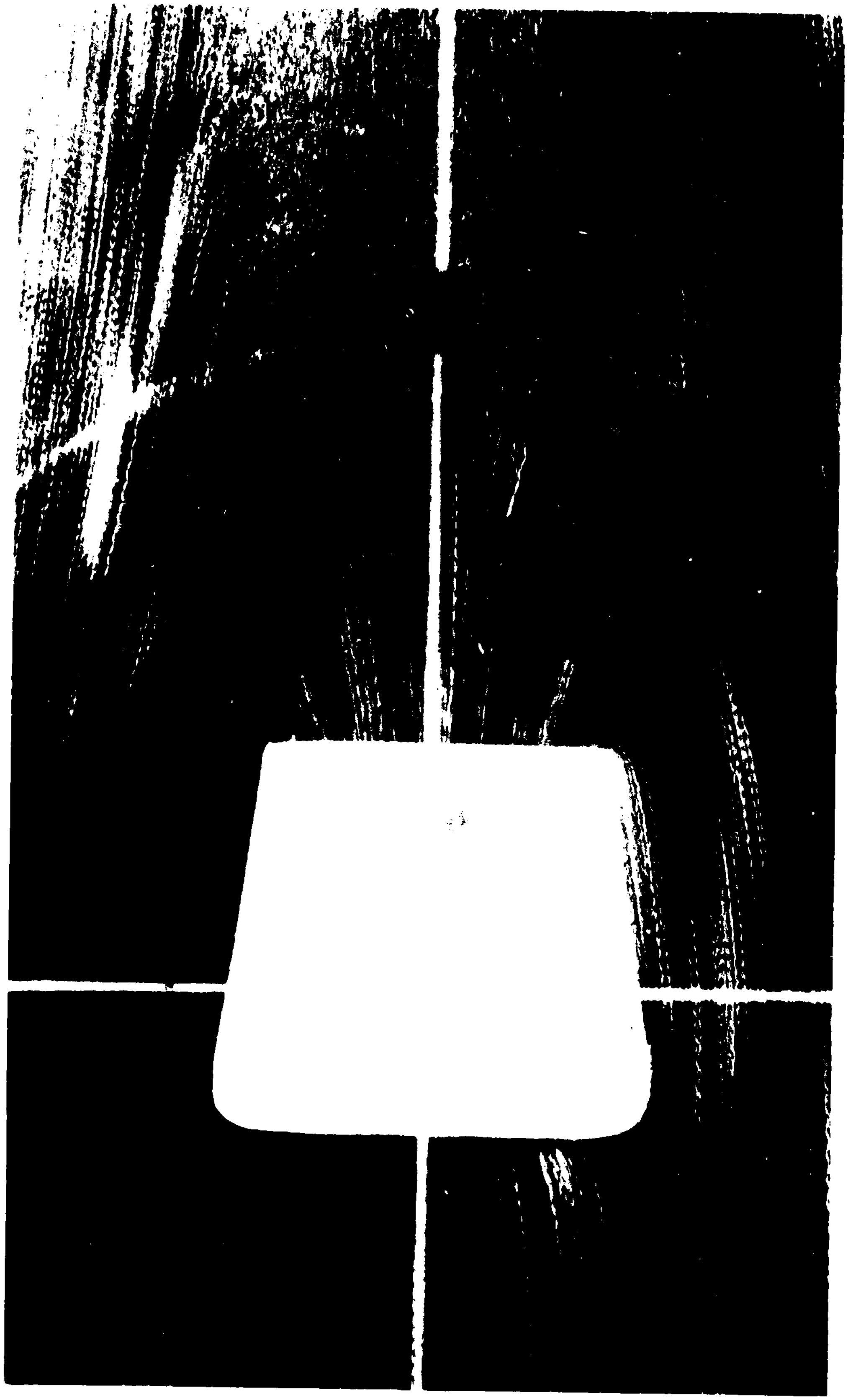


FIG. 11: ANNULAR JET BLOWING

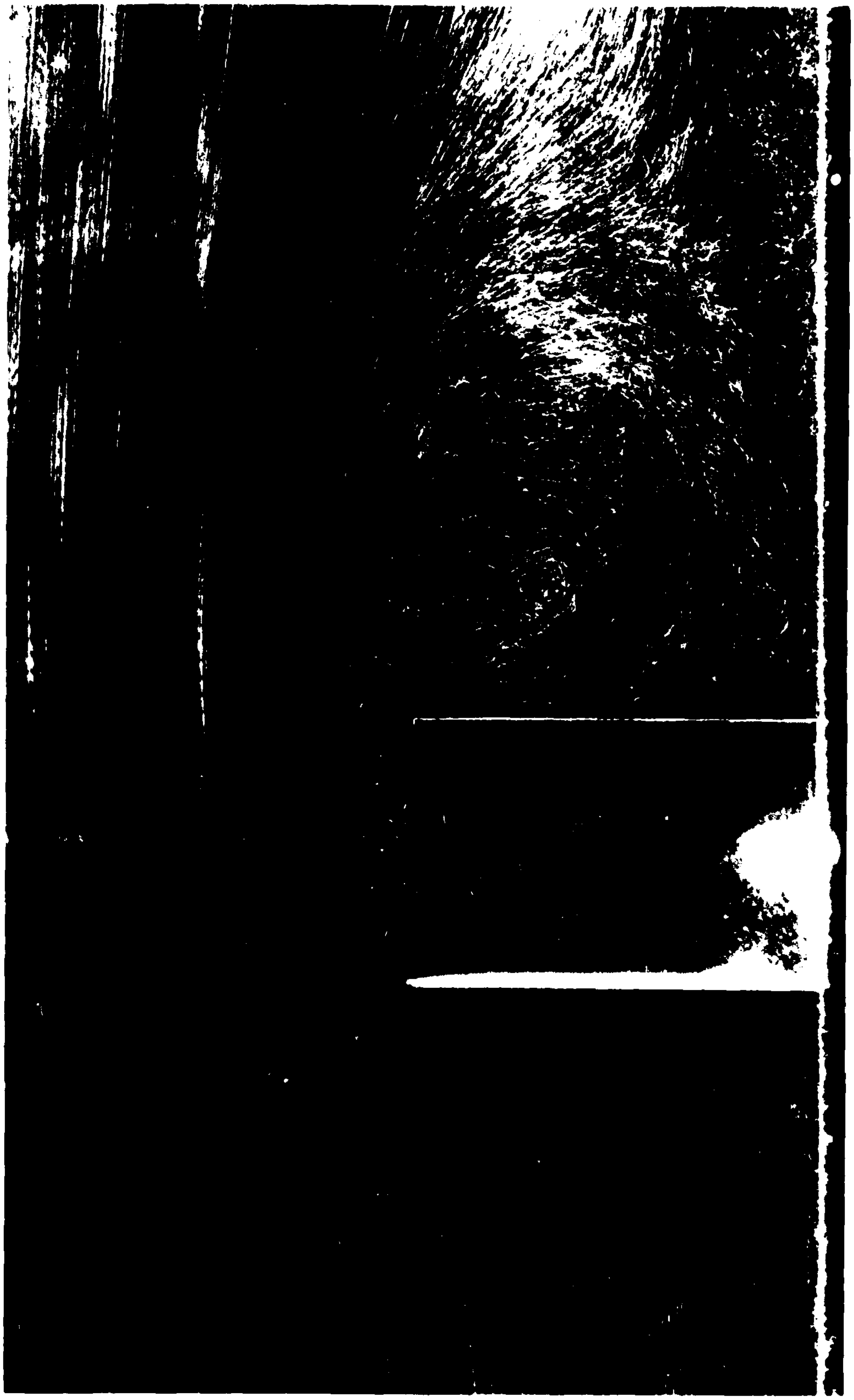


FIG. 12: WALL WAKE BEHIND A CUBE

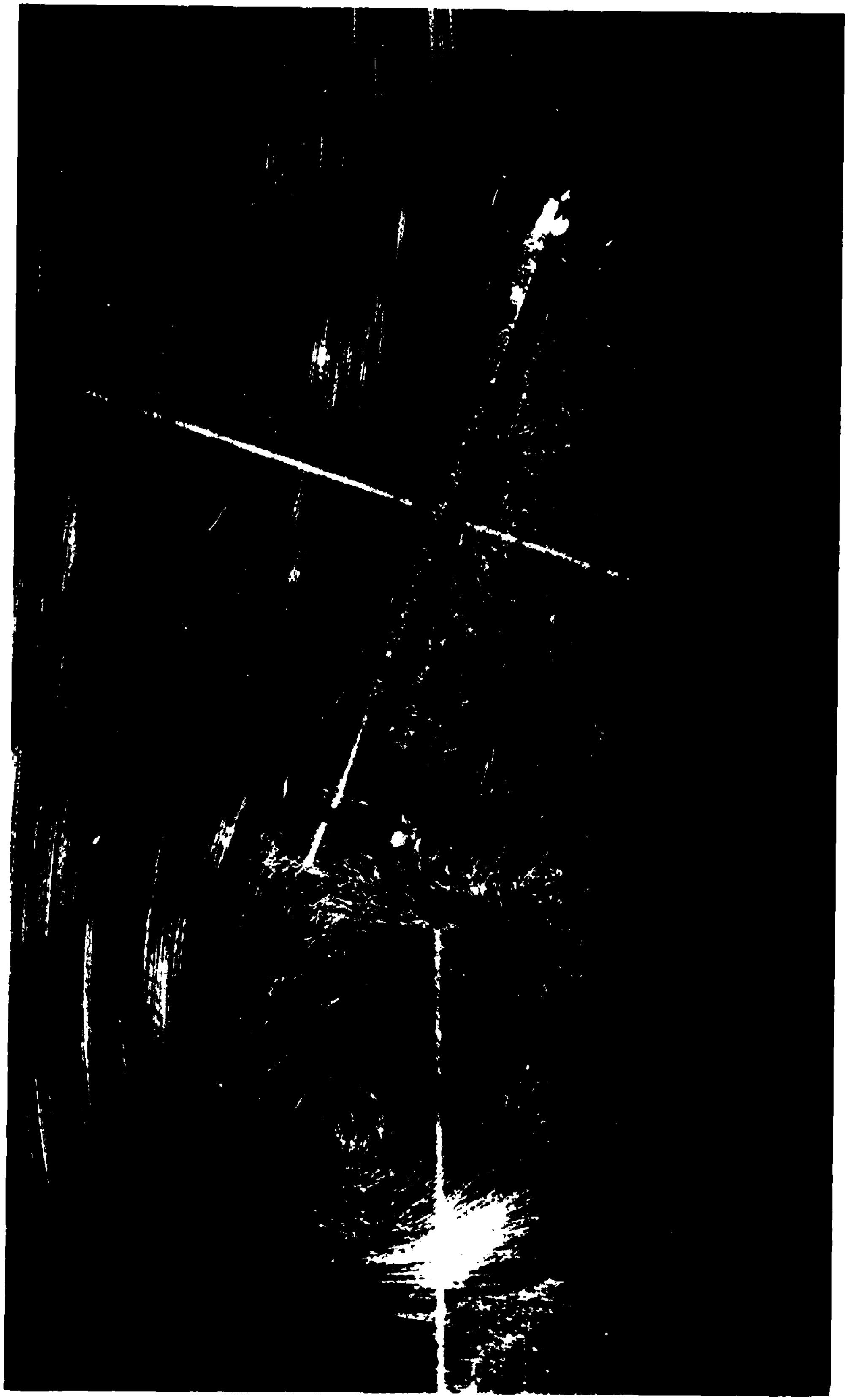


FIG. 13: FLOW OVER I BEAM

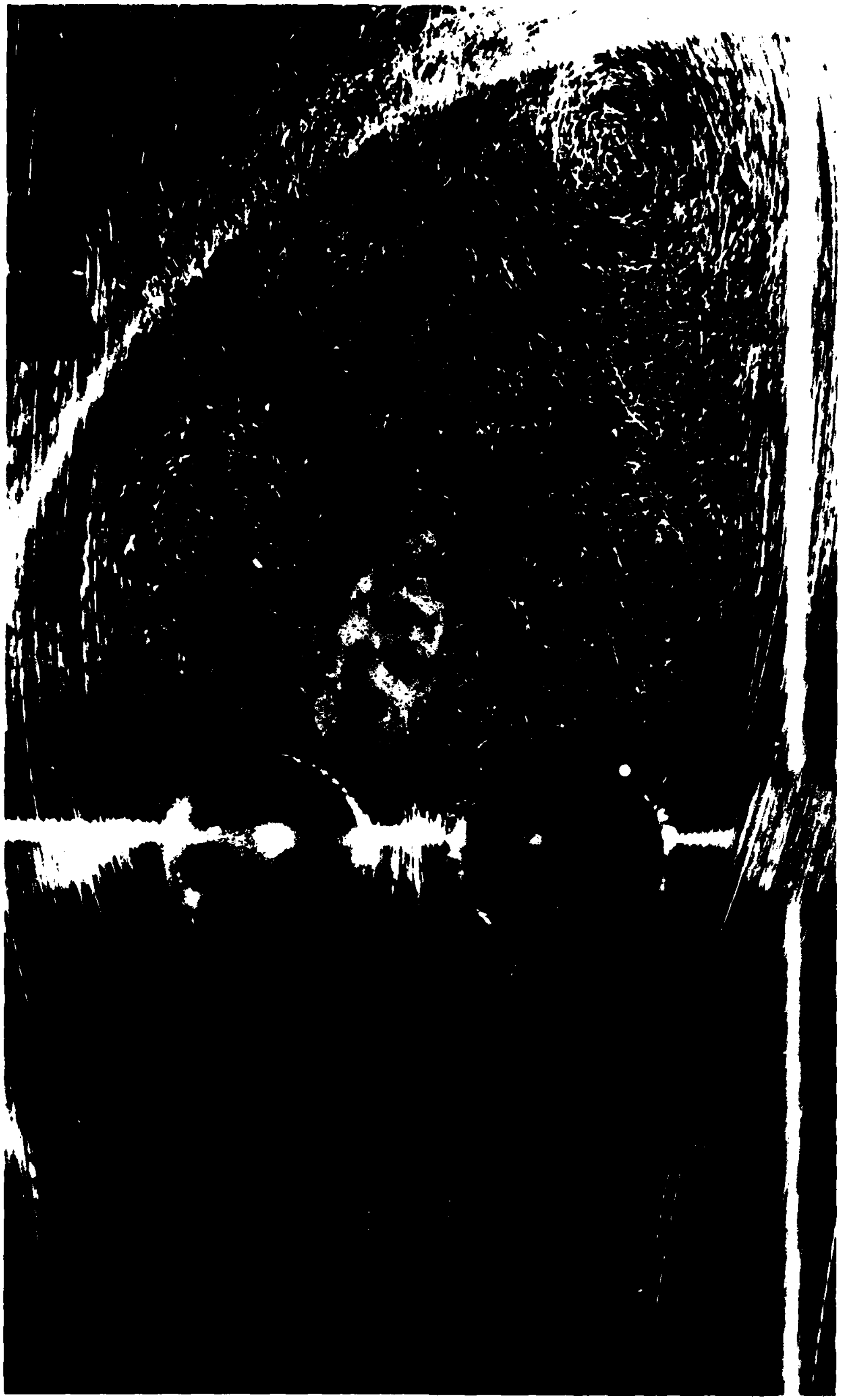
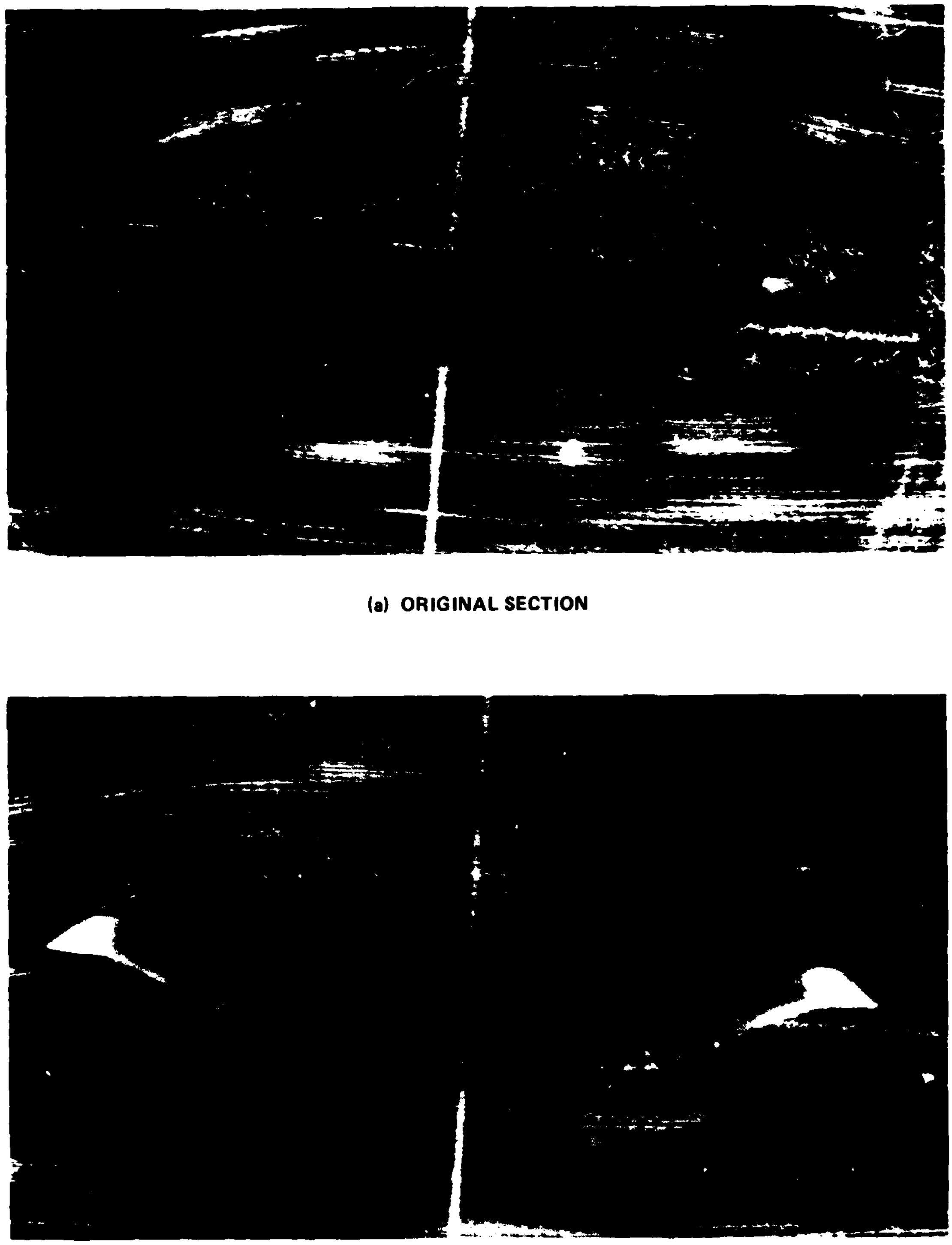


FIG. 14: TWO CABLES SPACED 1/2 DIAMETER



(a) ORIGINAL SECTION

(b) IMPROVED SECTION (EDGE EXTENSION)

FIG. 15: COMPARISON OF THE FLOW OVER BRIDGES

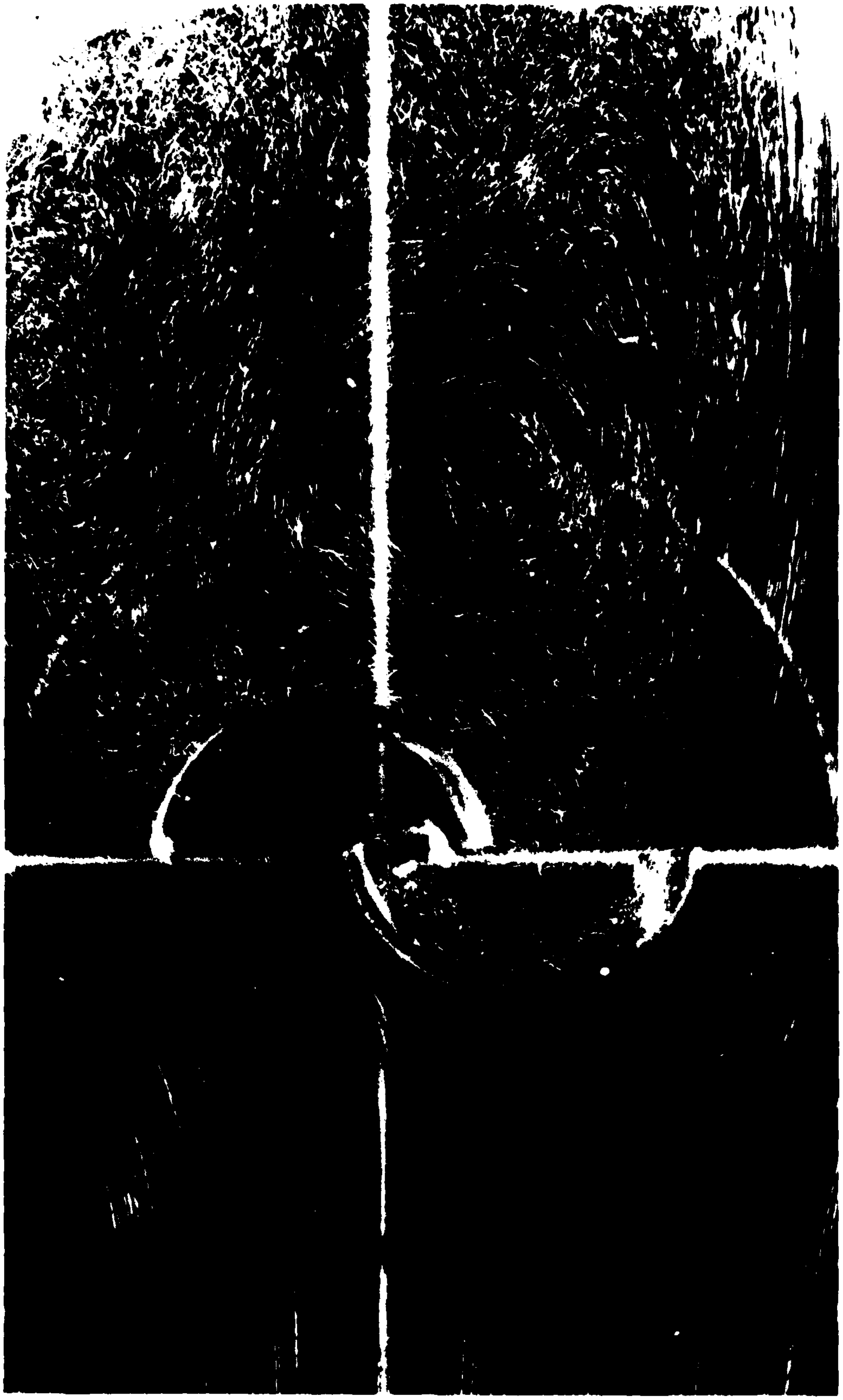


FIG. 16: SAVONIUS ROTOR

FIG. 17: VORTEX GENERATOR

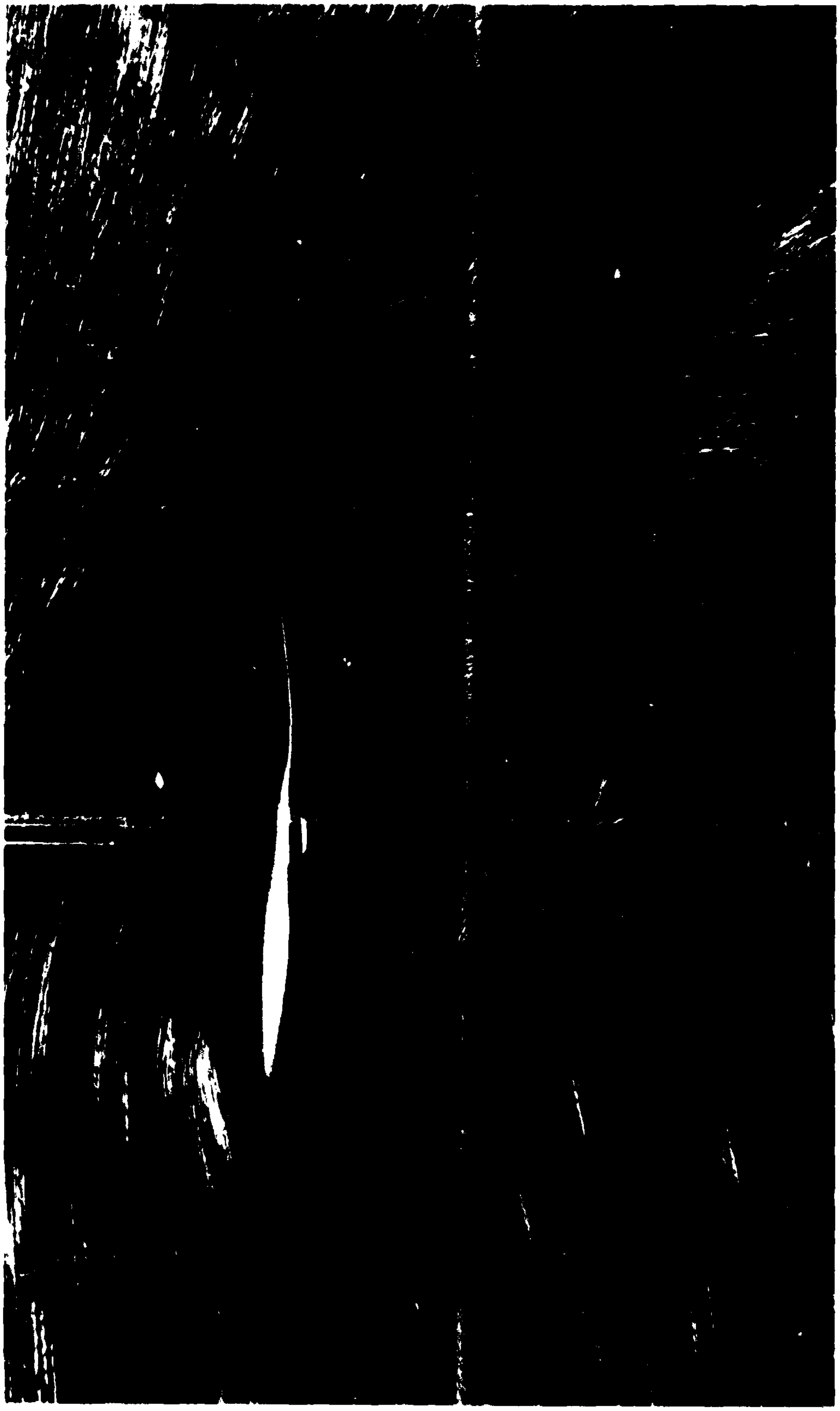


FIG. 18: FLOW THROUGH LIFTING PROPELLER

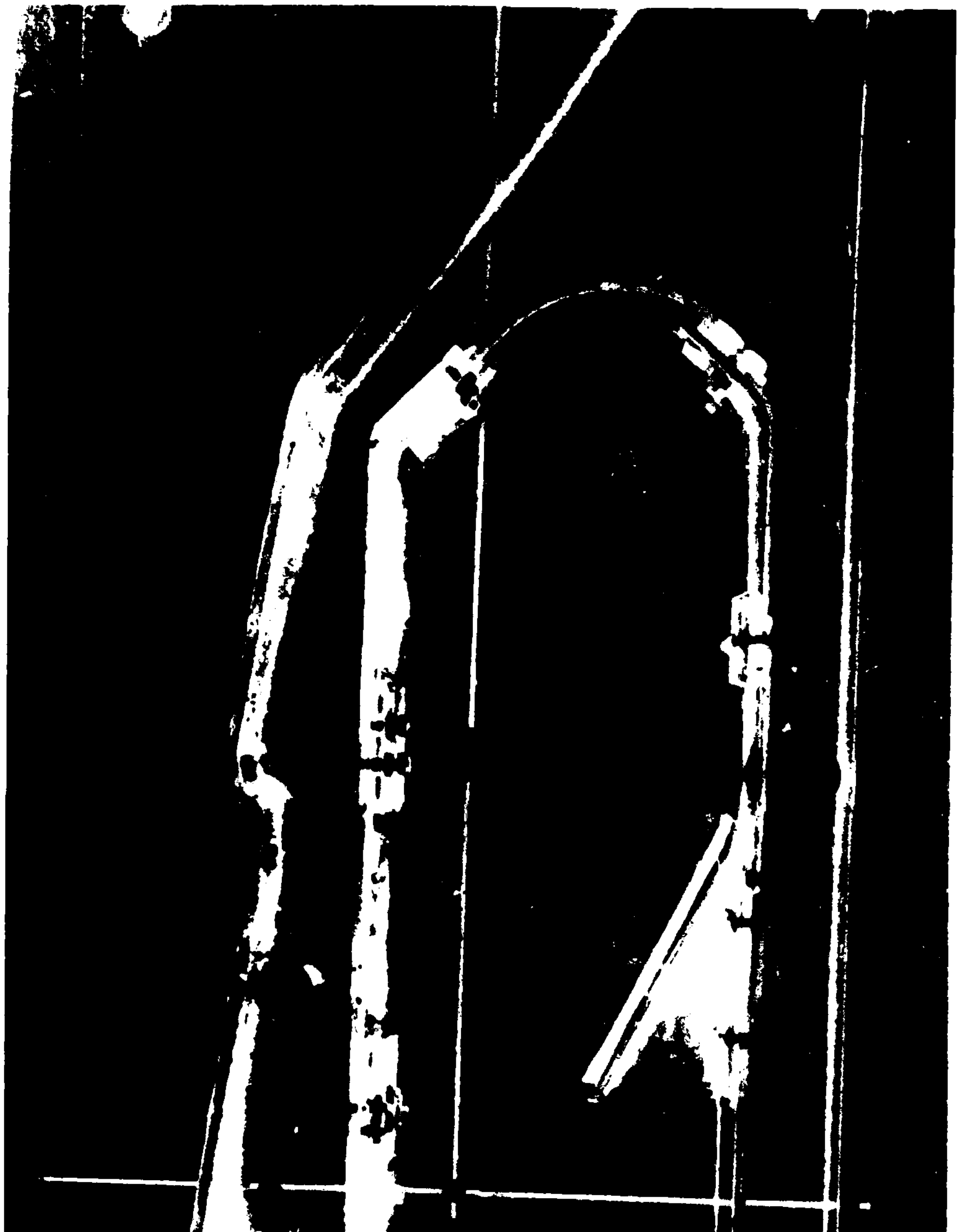


FIG. 19: CROSS SECTION OF THE FLAME TUBE (TURBO PROP ENGINE)

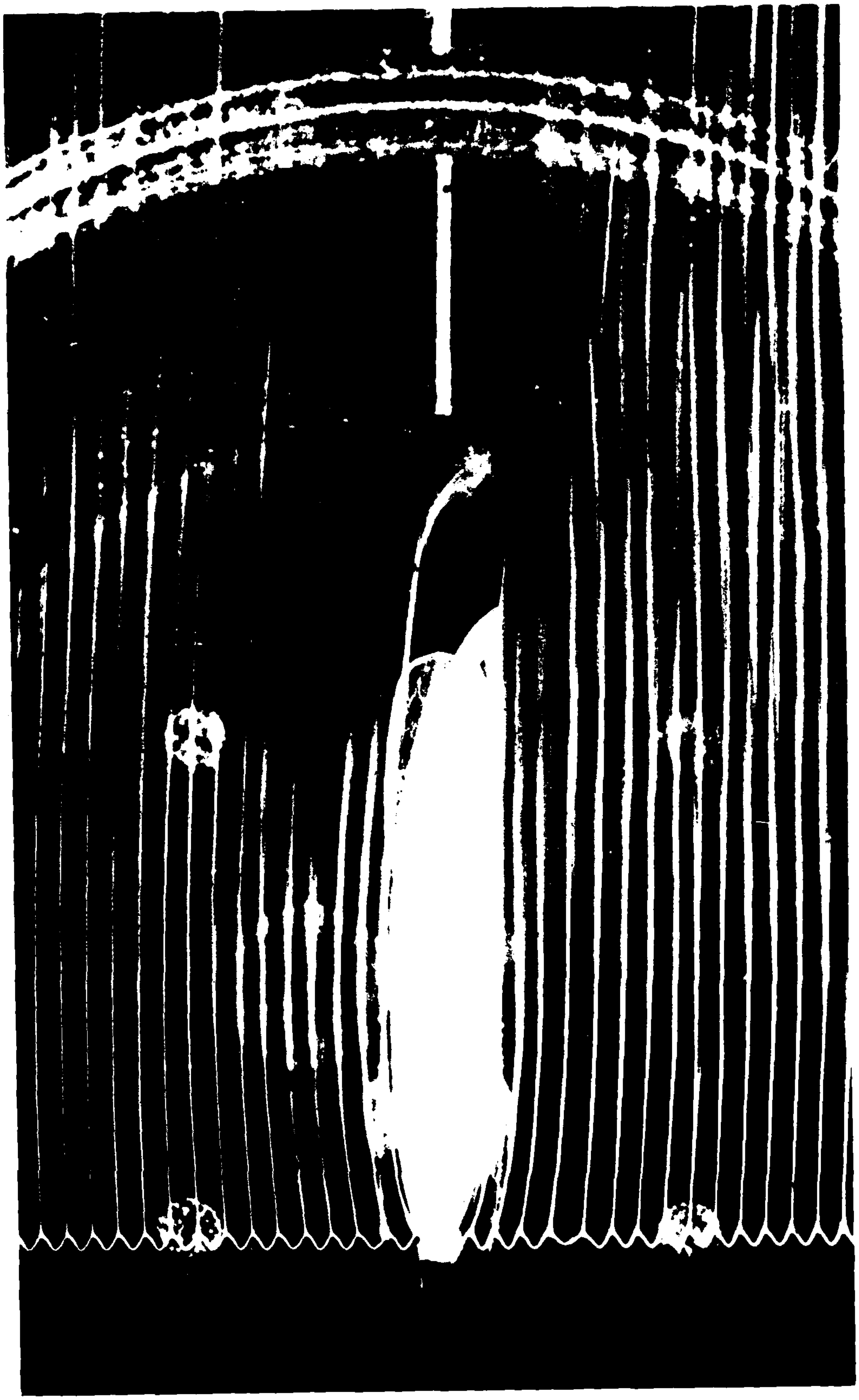


FIG. 20: HYDROGEN BUBBLE FILAMENTS PRODUCED BY KINKED PLATINUM WIRE

FIG. 21: VORTEX SHEET VISUALIZED BY HYDROGEN BUBBLES

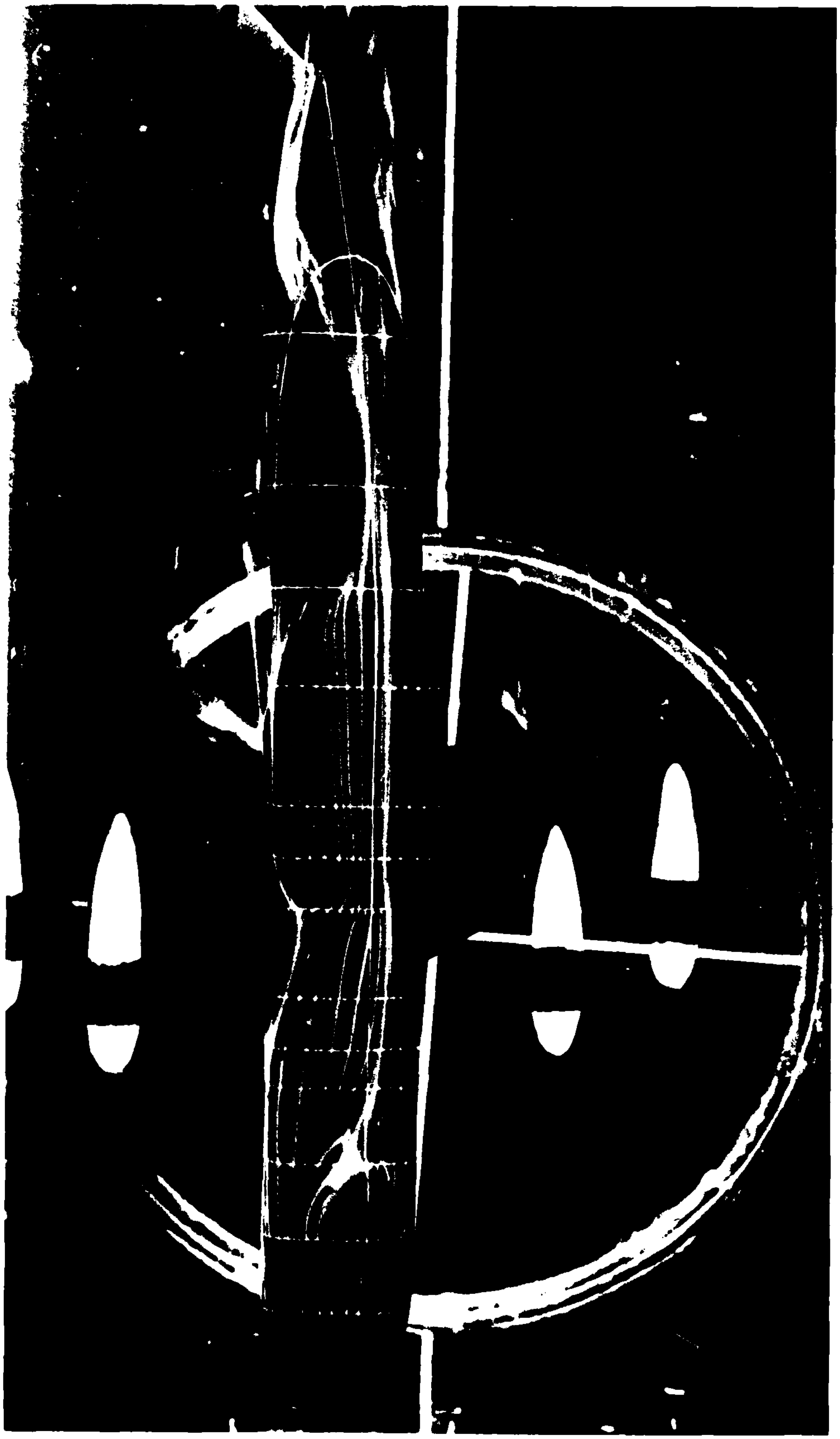


FIG. 22: BOUNDARY LAYER FLOW SEPARATION

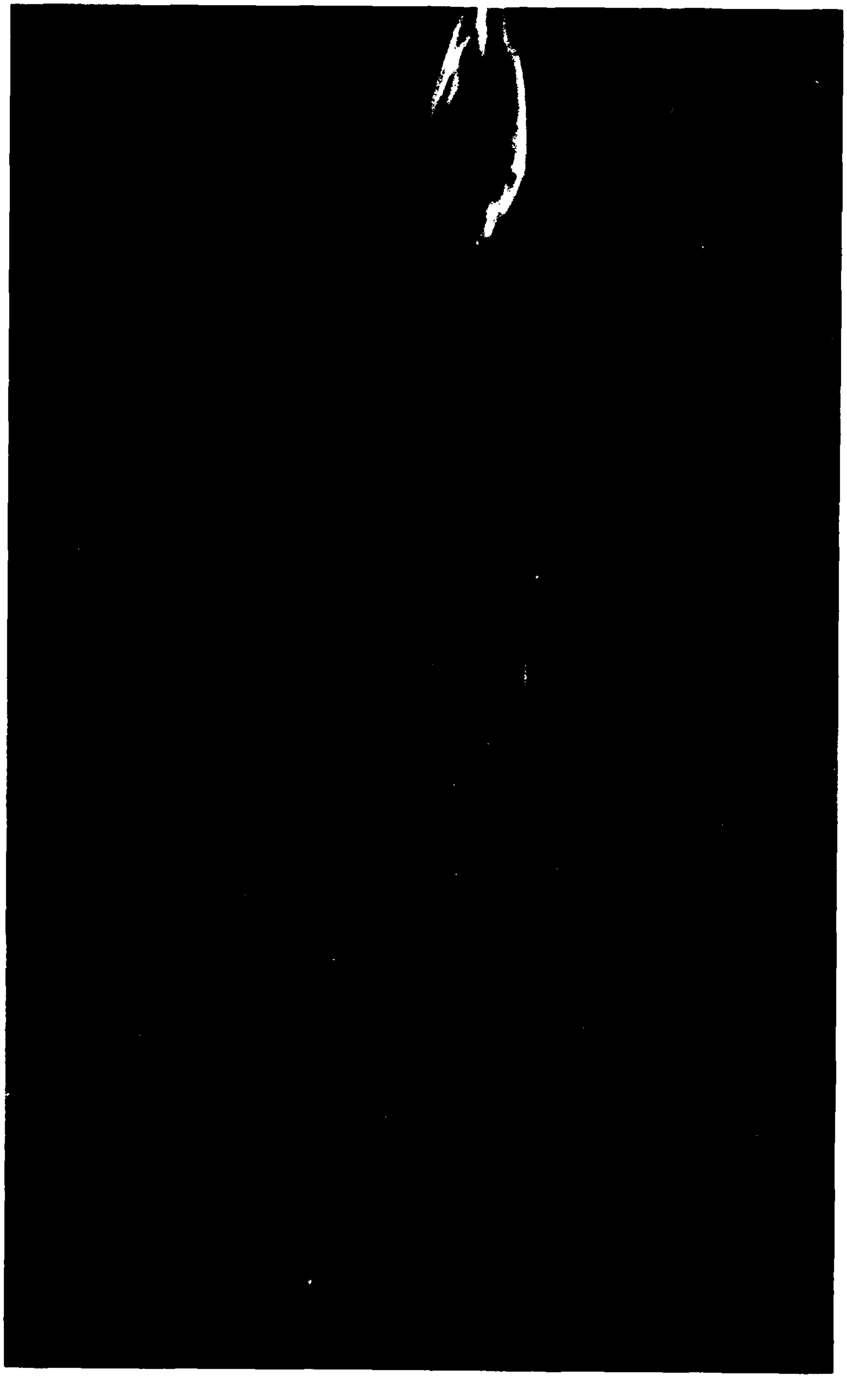


FIG. 23: ELLIPSOID – DECELERATION OF FLOW

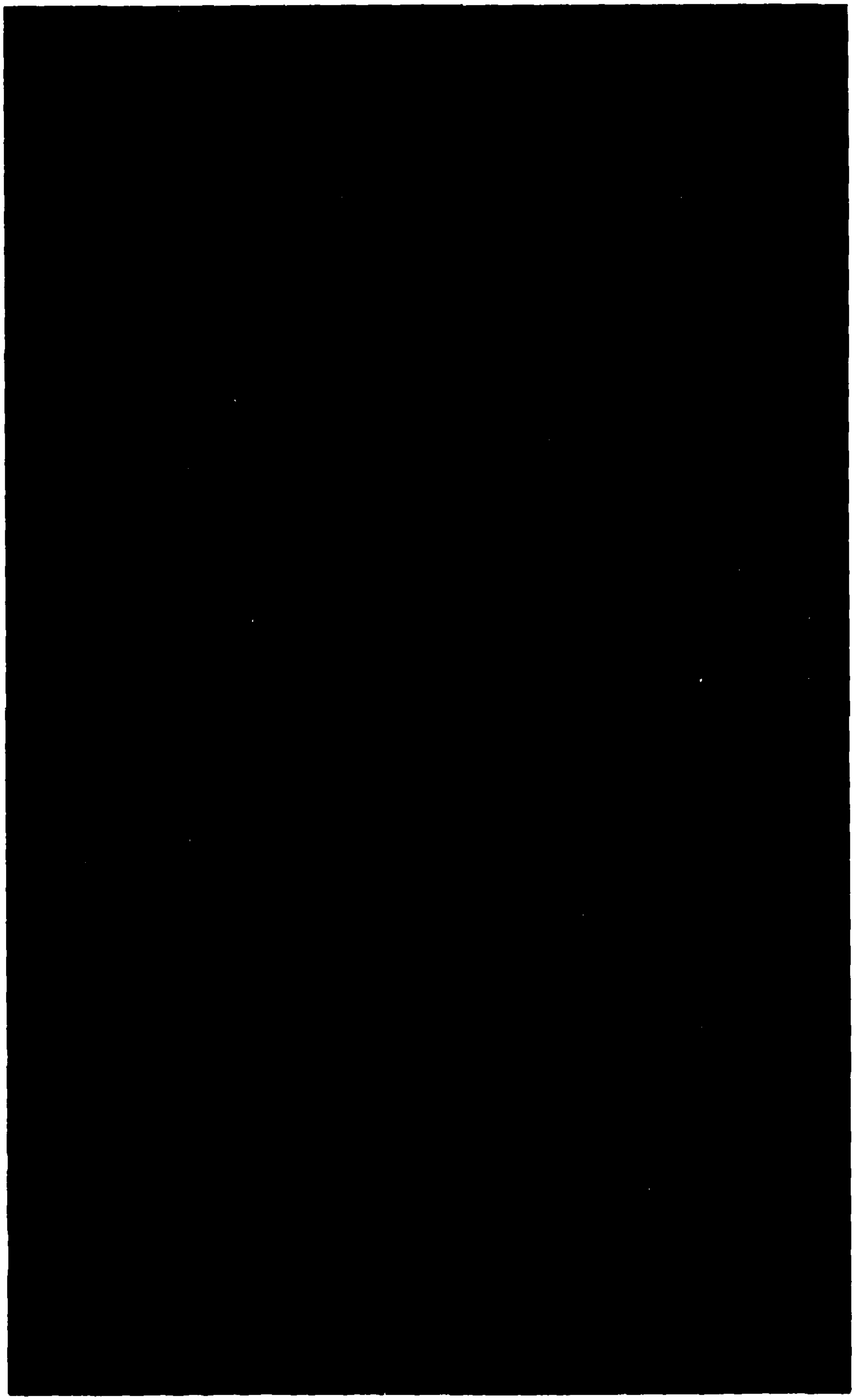


FIG. 24: FLUID LOGIC ELEMENT — UNINTERRUPTED LAMINAR POWER JET

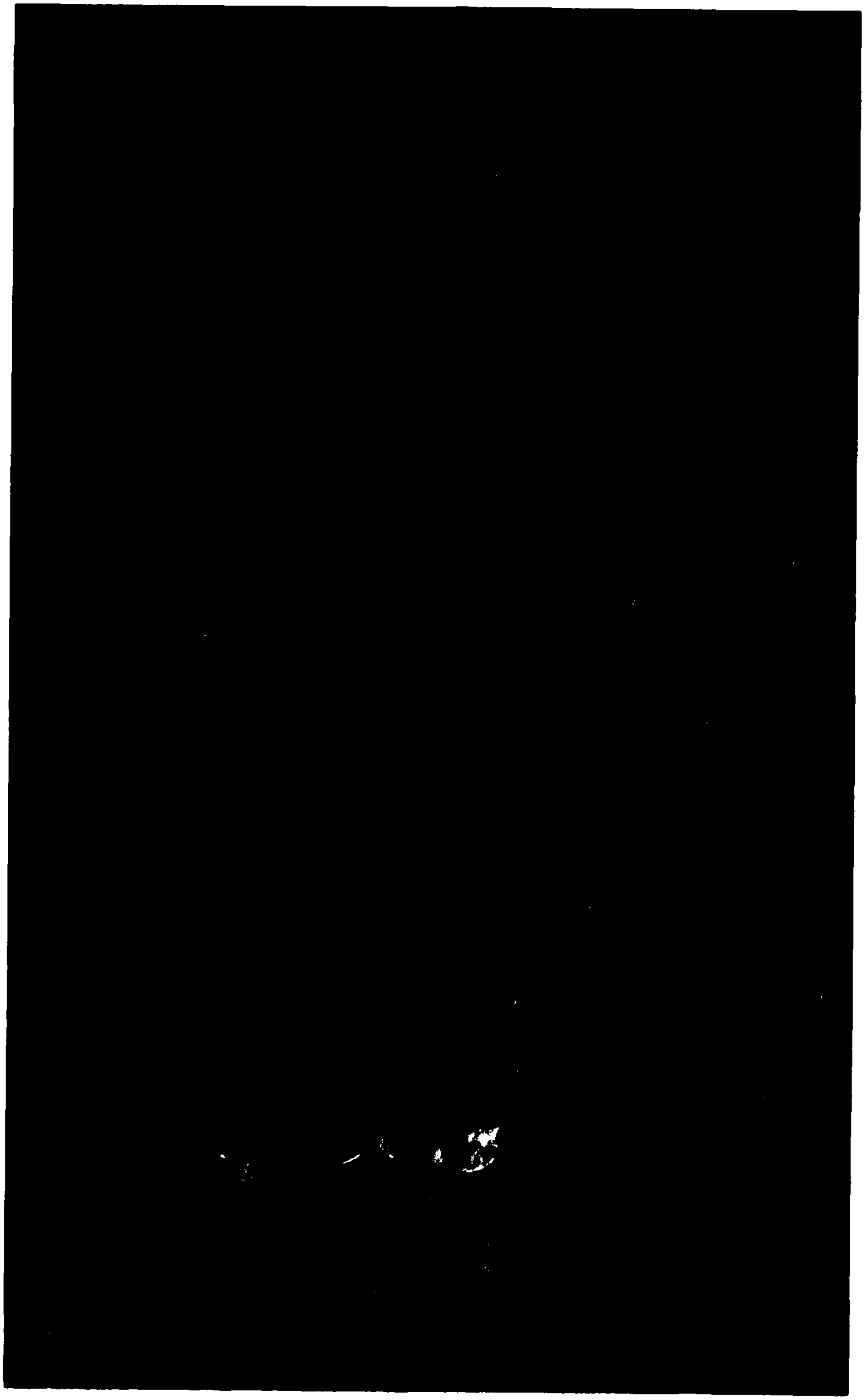


FIG. 25: FLUID LOGIC ELEMENT — POWER JET INTERRUPTED BY CONTROL JET

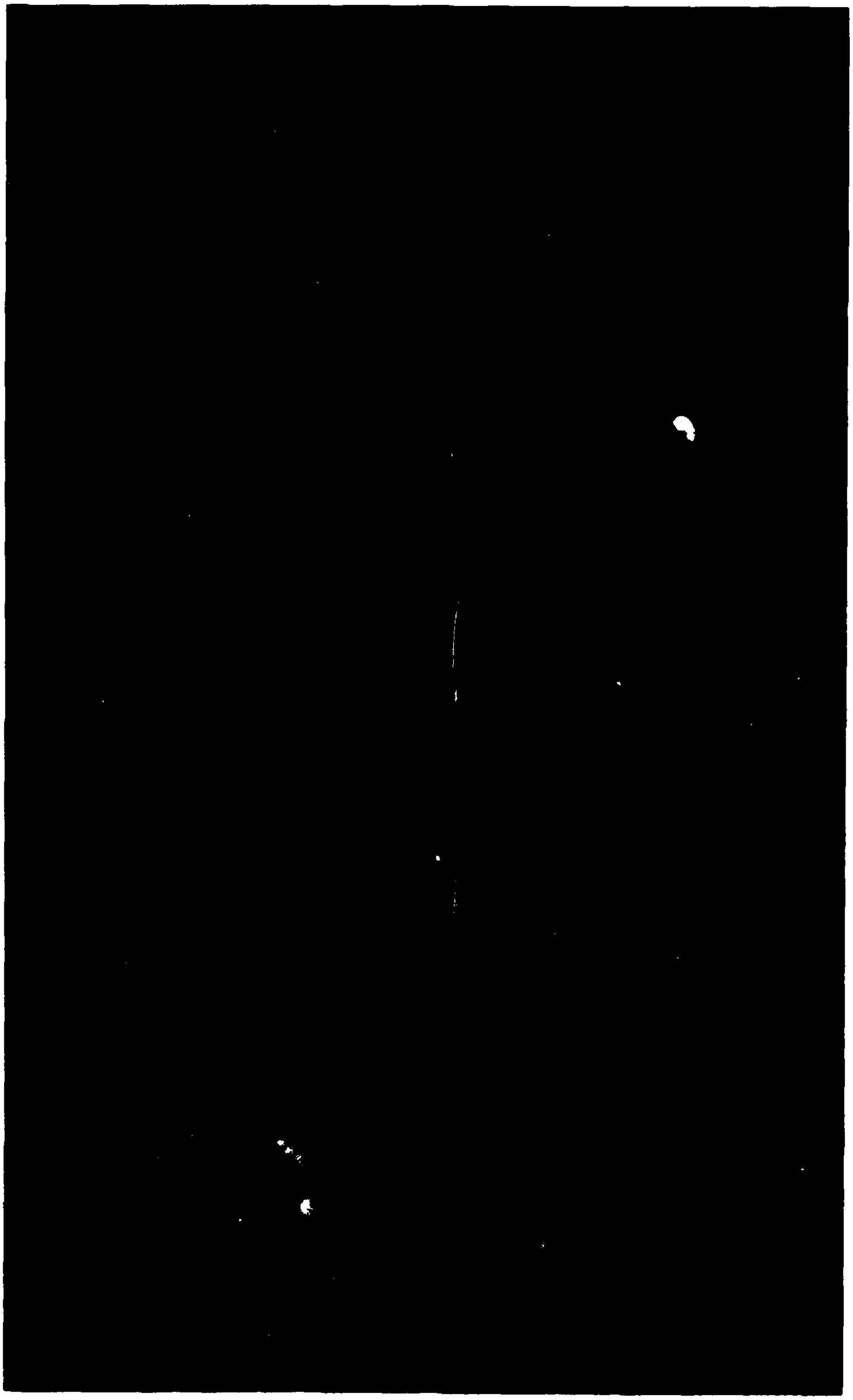


FIG. 26: MODERN AIRCRAFT WITH LONG FOREBODY — ANGLE OF ATTACK 25° — VORTICES SYMMETRICAL

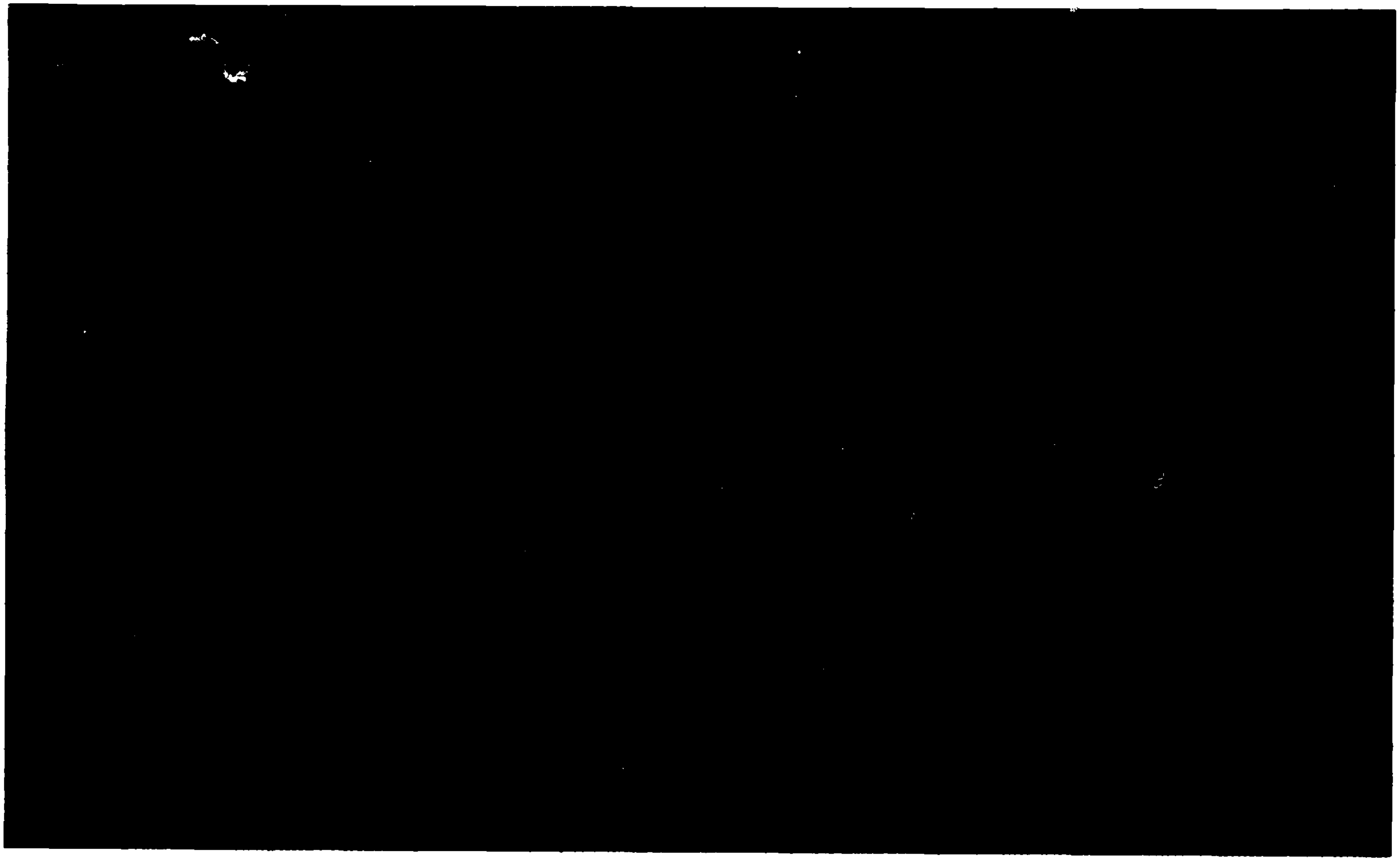


FIG. 27: MODERN AIRCRAFT WITH LONG FOREBODY – ANGLE OF ATTACK 45° – VORTICES ASYMMETRICAL

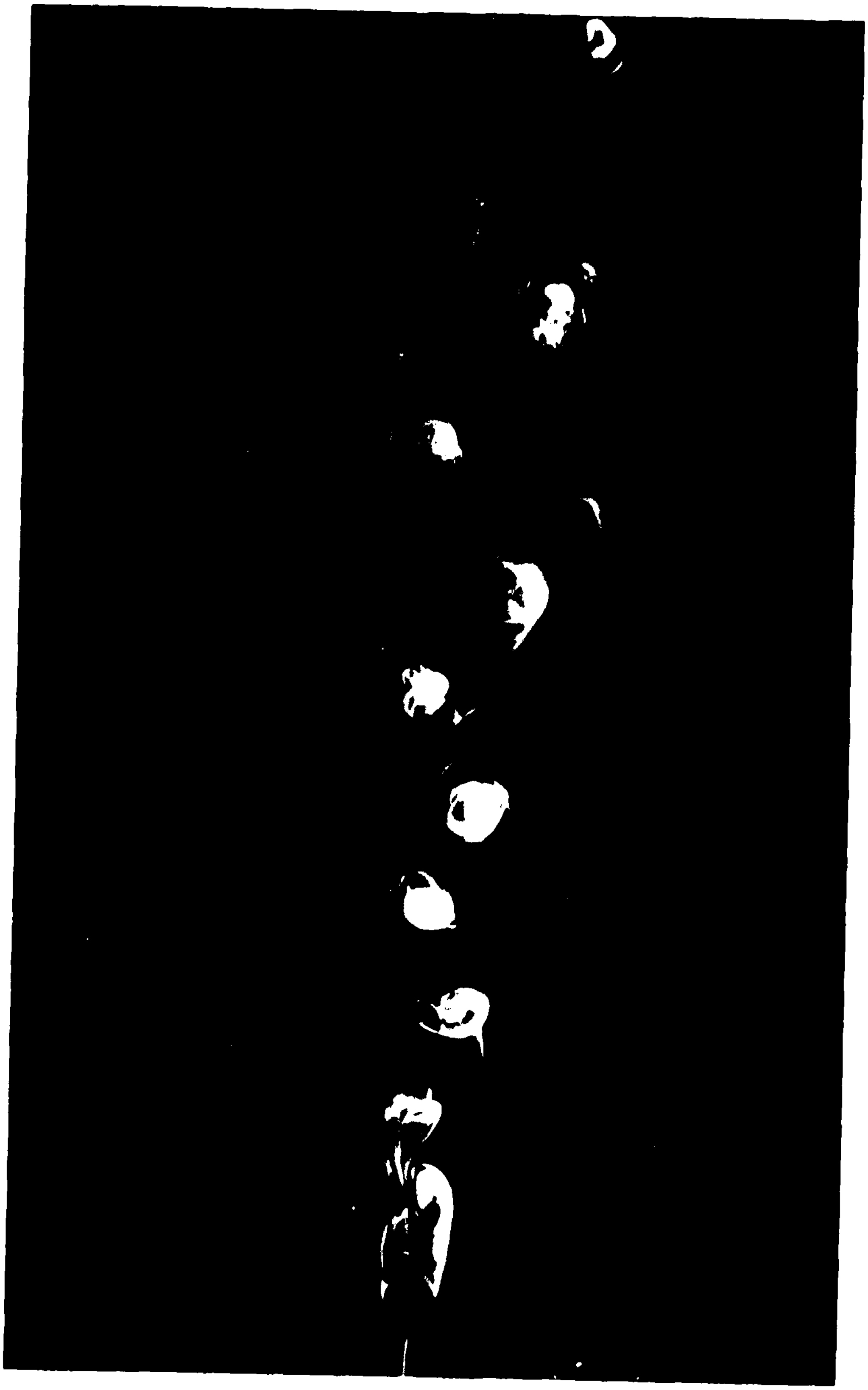


FIG. 28: VORTEX STREET

FIG. 29: VORTEX WAKE OF LIFTING FUSELAGE – SIDE VIEW

FIG. 30: VORTEX WAKE OF LIFTING FUSELAGE – REAR VIEW

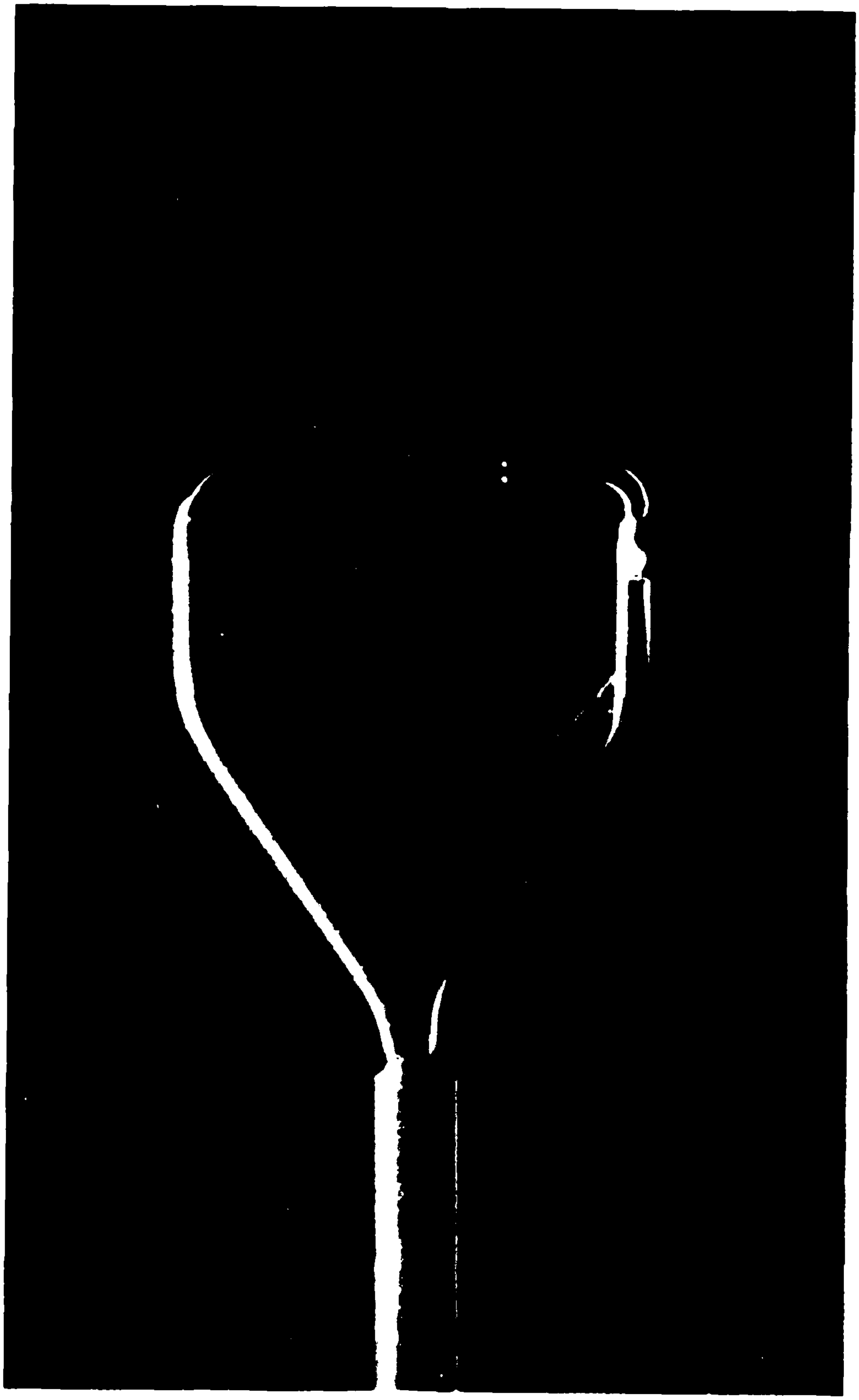


FIG. 31: FLUIDIC VELOCITY SENSOR

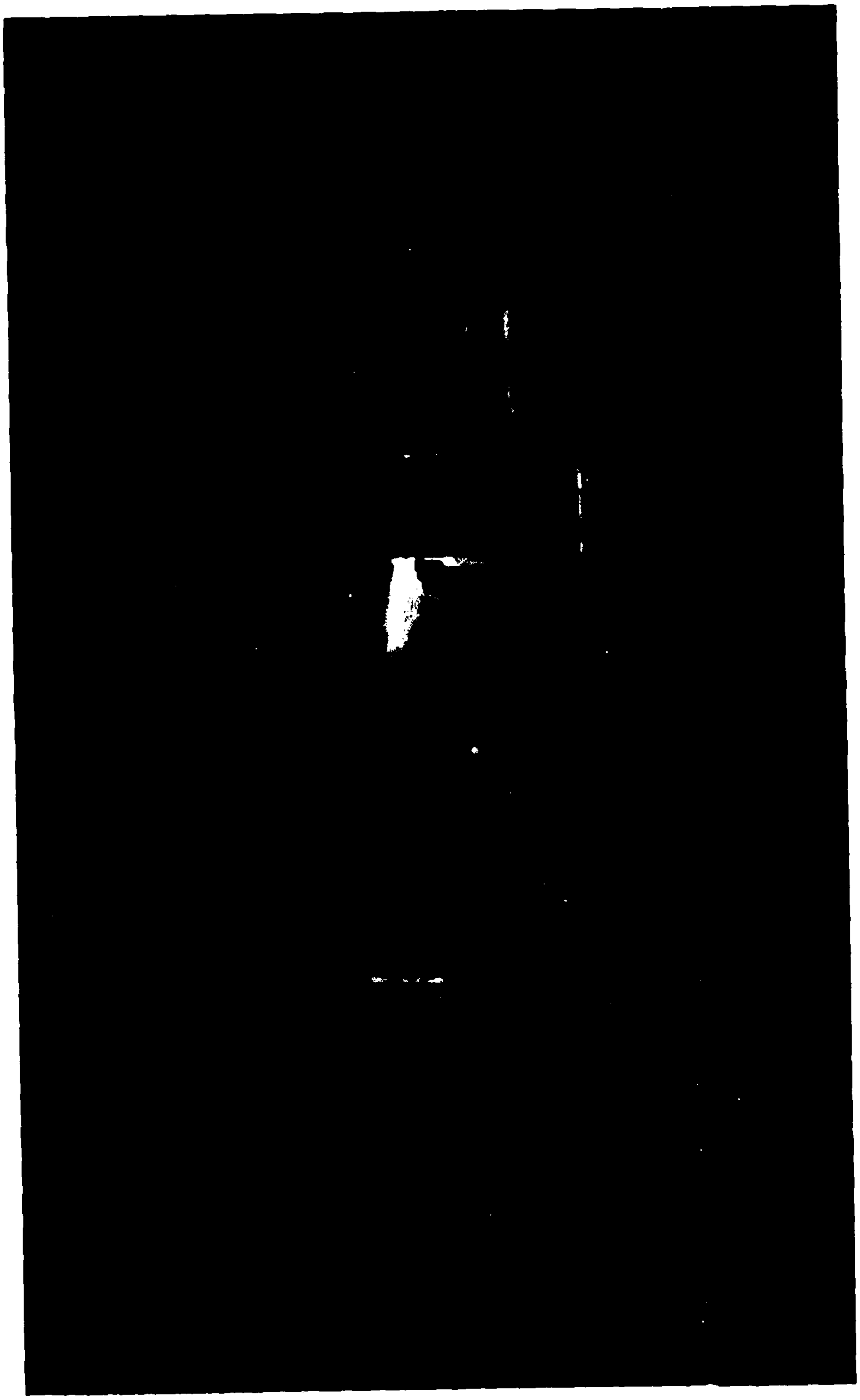


FIG. 32: SNOWPLOW TRUCK — ORIGINAL VERSION

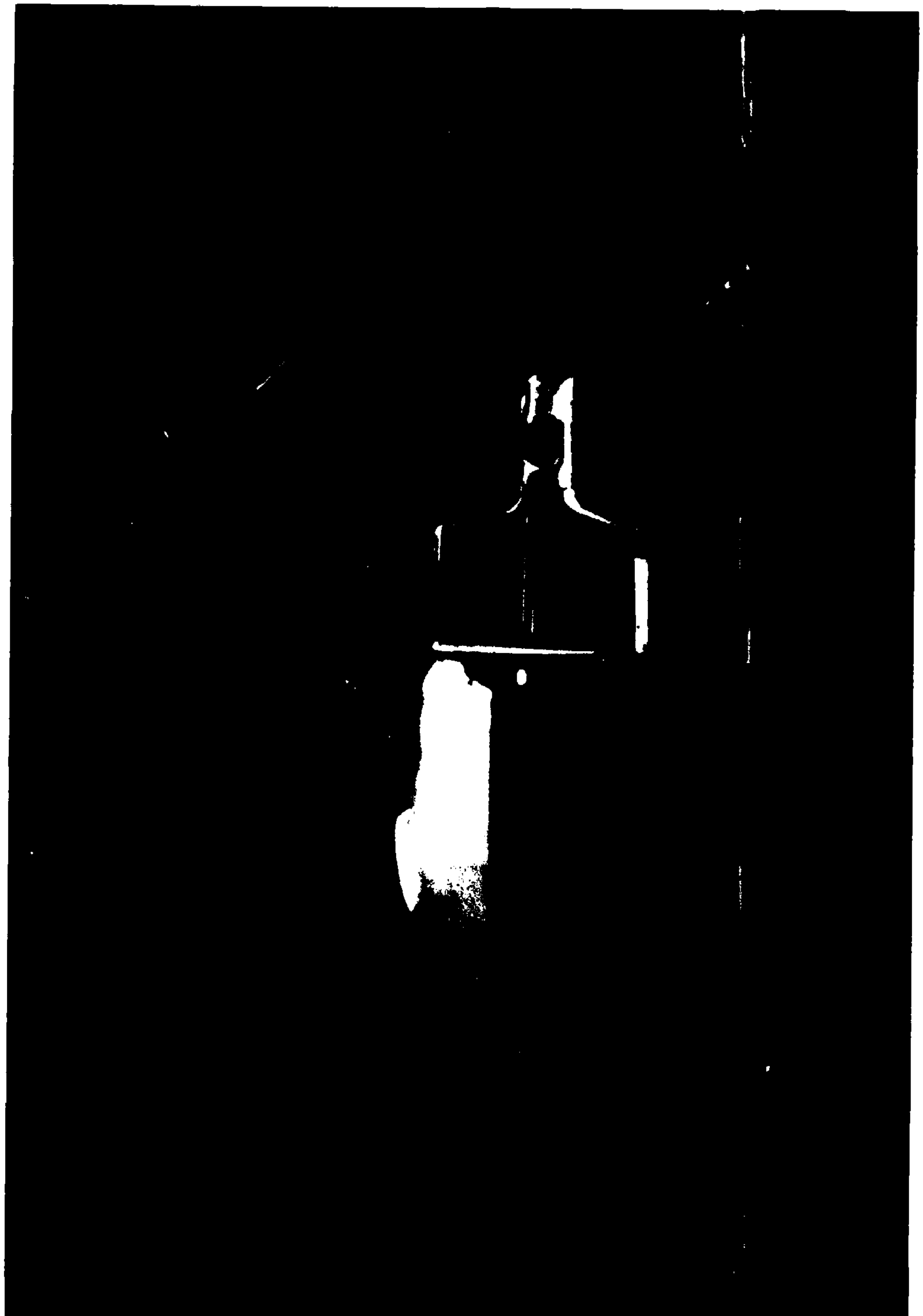


FIG. 33: SNOWPLOW TRUCK — IMPROVED VERSION

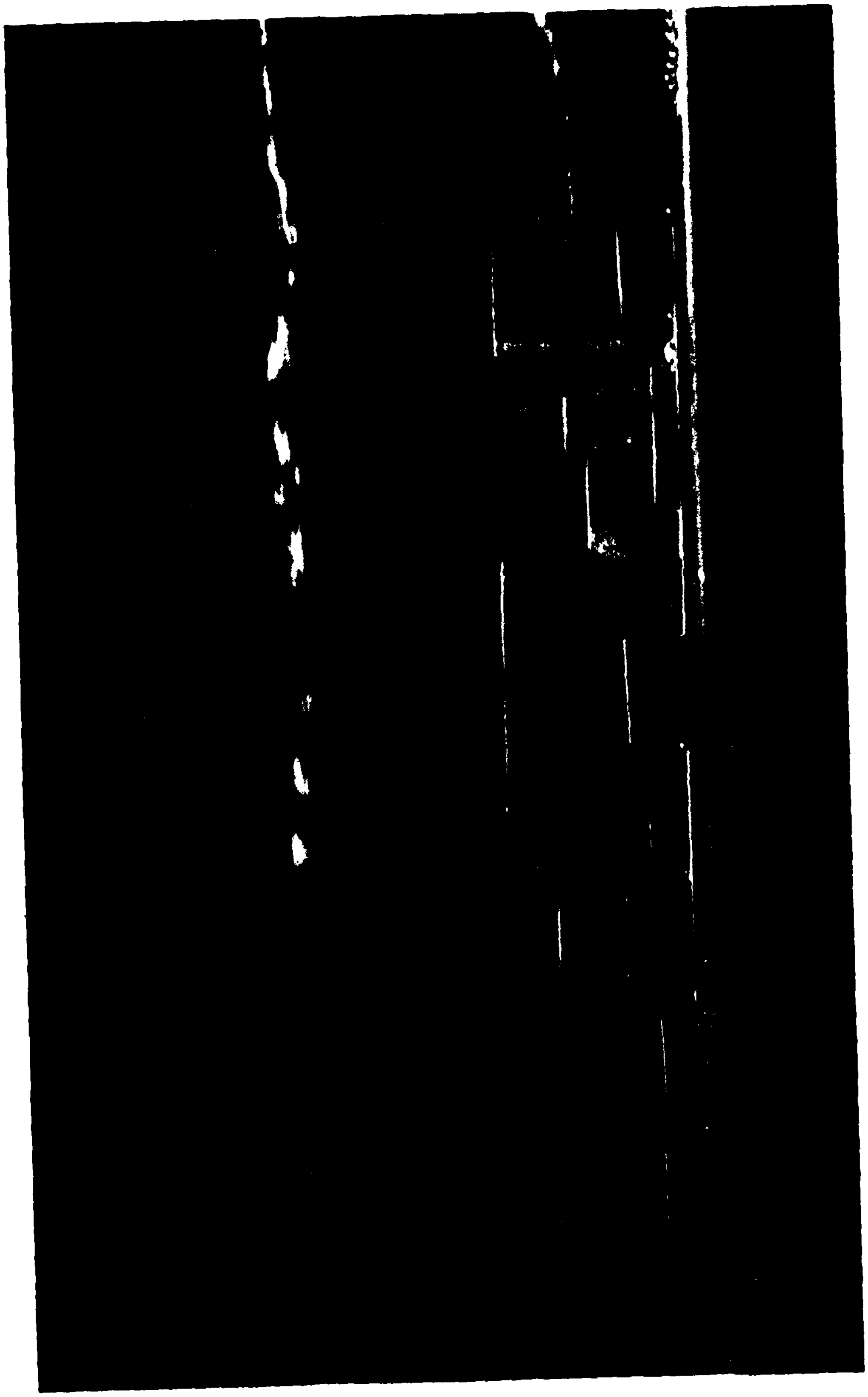


FIG. 34: GROUND WIND OVER CITY

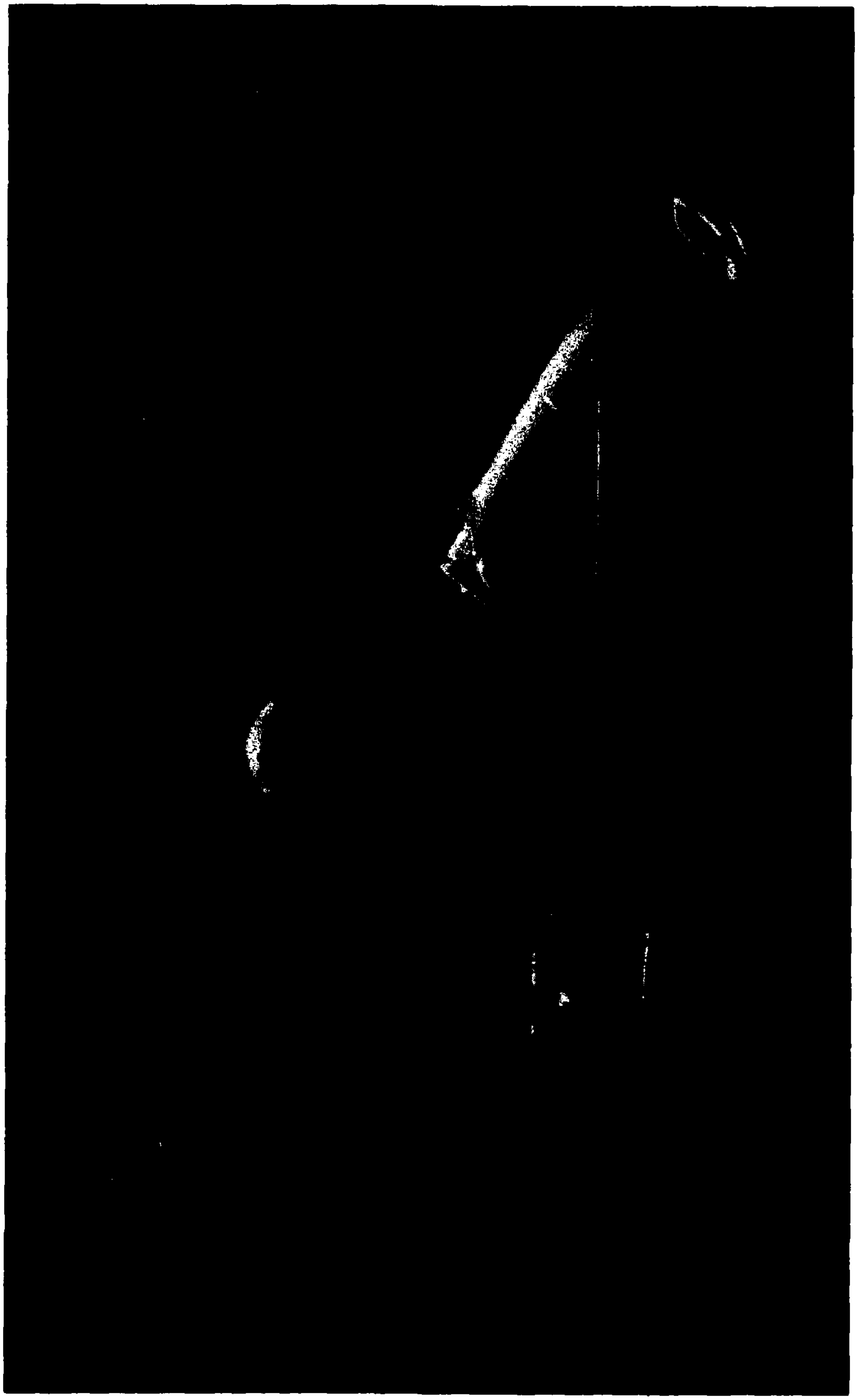


FIG. 35: SNOWMOBILE

FIG. 36: STREAMLINED MOTORCYCLE

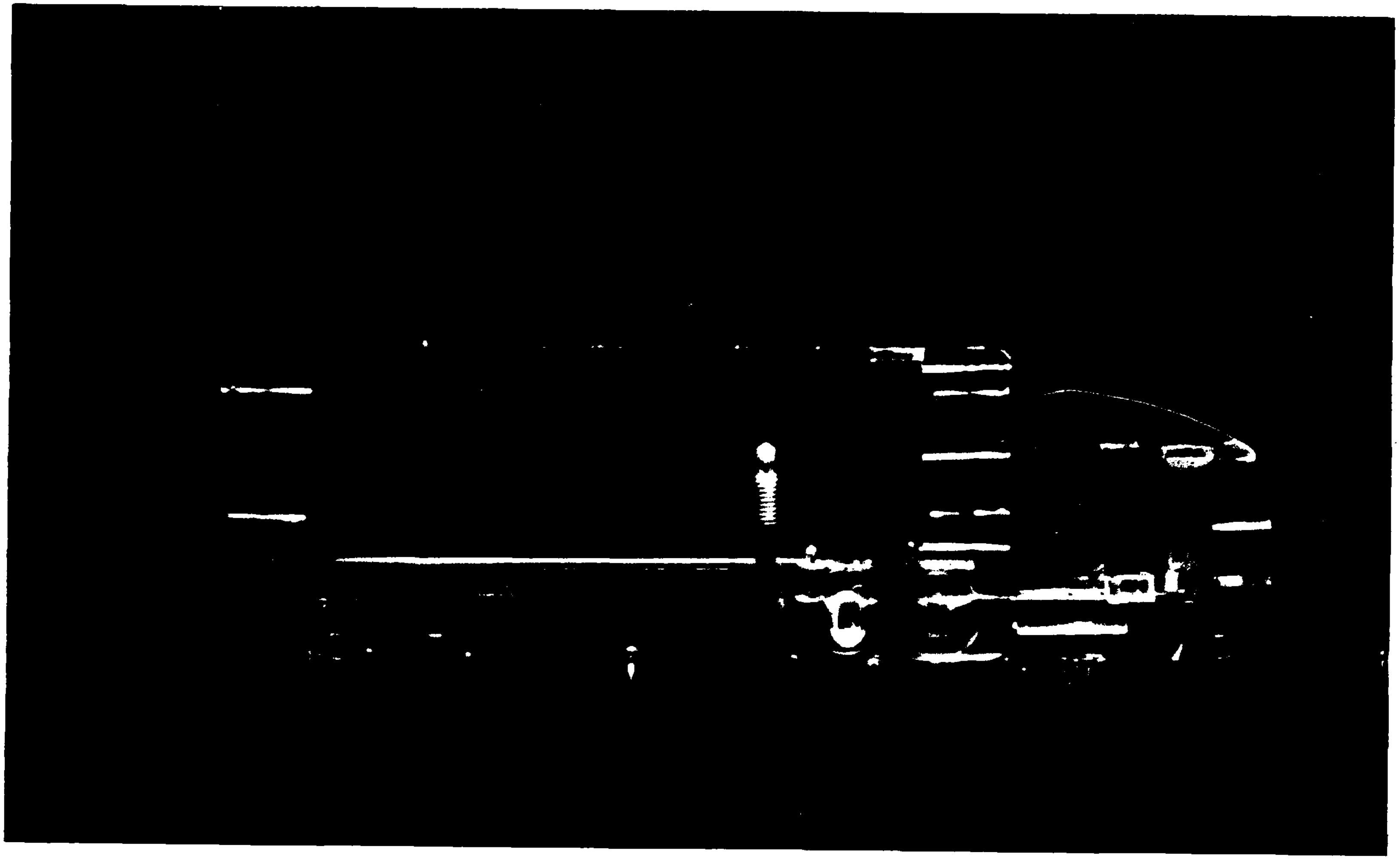


FIG. 37: TRUCK TRAILER – ORIGINAL VERSION

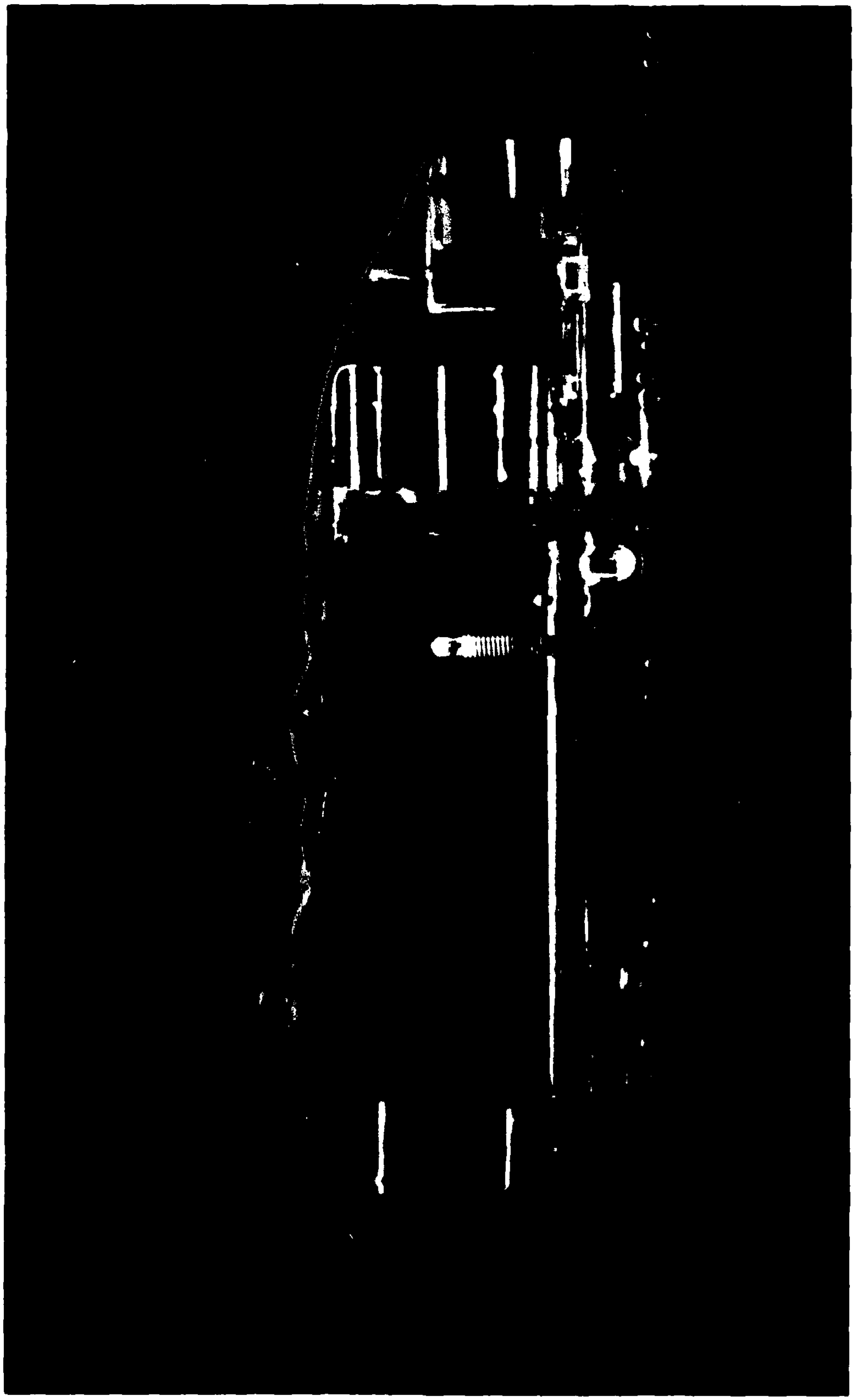


FIG. 38: TRUCK TRAILER — WITH DEFLECTOR ON CAB

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FLOW VISUALIZATION WATER TUNNEL – ITS CONSTRUCTION AND CAPABILITIES.
Dobrodzicki, G.A. April 1982. 53 pp. (incl. figures).

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A brief description of the facility and its ancillary equipment is followed by a short description of the flow visualization techniques.

To emphasize the diversity of subjects tested in the water tunnel, a list of typical experiments and a number of photographs are presented.

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